FRACTURE SURGERY

A Textbook of Common Fractures

Fracture Surgery

A Textbook of Common Fractures

HENRY MILCH, M D

Emeritus Attending and Consulting Orthopedic Surgeon
Hospital for Joint Diseases New York

AND

ROBERT AUSTIN MILCH, M D

Assistant Resident Surgeon
Peter Bent Brigham Hospital Boston

With a chapter on anesthesia by

HERBERT D DUBOVSKY, M D

Director of Anesthesiology,
Easton Hospital, Easton, Pennsylvania

WITH 671 ILLUSTRATIONS

A HOEBER-HARPER BOOK

Also by Henry Milch

Injuries and Surgical Diseases
of the Ischium

DEDICATED TO

THE MEMORY OF THE BELOVED

MORRIS SALZBERG

1877—1955

FRACTURE SURGERY

A Textbook of Common Fractures

Printed in the United States of America

A I

For information address PAUL B HOEBER INC
Medical Book Department of HARPER & BROTHERS
49 East 33rd Street New York 16 N Y

Library of Congress catalog card number 58 7399

CONTENTS

PREFACE

The present work has been prepared in an attempt to bridge the gap between the small handbook of fracture management and the encyclopedic volume encompassing material primarily of interest to the specialist It makes no pretense of being either a roentgenographic atlas or a complete treatise on fractures or fracture therapy The book is the outcome of the problems confronting the intern or resident in the emergency ward of a large hospital, when the urgent call makes a ready reference work of largely pictorial nature highly desirable

In accordance with the basic therapeutic principle of aligning the axis of the distal fragment with that of the proximal, the various fractures have been analyzed and discussed primarily in the light of their axial malalignments The clinical consequences and the roentgenographic recognition of the various axial alignments have been described The clinical material and illustrations have been chosen to explain most clearly the emergency diagnosis and definitive treatment of the more commonly observed fractures

The universal use of the x-ray for the purpose of diagnosis has reduced detailed history-taking, careful analysis of probable causative mechanisms, and clinically diagnostic criteria largely to the level of academic exercises Such material has therefore been either deemphasized or entirely omitted We believe that the consideration of pathologic fractures, of the multiple spontaneous fractures characteristic of certain metabolic disturbances, of fracture complications such as fat embolism, thrombophlebitis, pulmonary infarctions, and other problems falls more appropriately within the purview of larger reference works

This volume is particularly planned for the medical student and the surgical house officer, those at the beginning of their study of fractures as well as the general practitioner who does not devote full time to the treatment of fractures and to whom a fracture is a small and frequently unexpected part of practice It will achieve its purpose if it aids these physicians in taking care of the patient and, where possible, of the fracture itself through the various phases of fracture management

In the two years during which the present work was completed, a gratifyingly large number of persons have given the writers much in the way of wise counsel, generous aid, and above all else, steady encouragement to see the job through It would be unfair both to them and to the reader to list all their names here We cannot, however let the opportunity pass entirely without expressing to our friends, named and unnamed our grateful thanks

We cannot adequately express to Pearl S Milch our gratitude and kind feelings

Section IV
The Appendicular Skeleton
Lower Extremity

SECTION I

General Considerations

for her constant encouragement, which in a very real sense has been responsible for the ultimate publication of this book

To June M Dubovsky we should like to express our unbounded gratitude for her tireless industry in converting our thoughts into clear, concise illustrations of the highest quality and, in so doing, clarifying concepts that were often nebulous

We wish to note with special thanks the unstinted assistance and kind suggestions of Mrs E Lindemann We are indebted, too, to the authors of numerous texts and to the editors of a number of journals who have granted us permission to reprint from their publications Our thanks are also due to Dr David F Smith of the Davis and Geck Company for helping us with details of plaster manufacture and to the various concerns noted in the text for permission to reproduce photographs of standard pieces of their fracture equipment

Finally, we wish to express to Mr Paul B Hoeber, our publisher, and to Mrs Eunice Stevens, his editor our appreciation for the many courtesies and kind co operation they have shown us during the production of this book

H M
R A M

CHAPTER 1

Emergency Care

In the emergency situation, too much attention is paid to the fracture and far too little directed to the patient as a whole Craniocerebral, intrathoracic, or intraabdominal trauma is not infrequently associated with severe or multiple injuries in which fractures are likely to occur and must be sought in every fracture These are often asymptomatic in the beginning, and narcotics or other drugs that may mask or exacerbate symptoms resulting from injuries in these regions should not be administered until the possibility of such trauma has been unequivocally excluded

General Care of the Patient

The welfare of the patient as a whole takes precedence over the treatment of any fracture Primarily, this involves (1) preservation of a properly functioning airway (2) control of hemorrhage, and (3) prevention of shock

In an unconscious patient maintenance of an adequate airway may require nothing more complicated than placing the patient in a semiprone position In this position, aspiration of bronchial secretions and vomitus or dropping back of the tongue is least likely to occur If the tongue persistently drops back against the pharyngeal wall it must be pulled forward and, if necessary, held forward by a suture or clamp through its tip

The patency of the airway may be preserved by the insertion of an oropharyngeal nasopharyngeal or endotracheal tube, which should be secured to the patient s head Where there is evidence of laryngeal obstruction emergency tracheotomy may be necessary This should be performed through a longitudinal incision just above the episternal notch Where a partially patent airway suggests the probable necessity of a subsequent tracheotomy, this should be performed as soon as the indication arises through an elective, transverse thyroid type of incision

Control of hemorrhage is the next most important consideration with respect to maintenance of the patient s circulating blood volume, the prevention of shock, and management of the local wound

CHAPTER 1

Emergency Care

In the emergency situation, too much attention is paid to the fracture and far too little directed to the patient as a whole Craniocerebral, intrathoracic, or intraabdominal trauma is not infrequently associated with severe or multiple injuries in which fractures are likely to occur and must be sought in every fracture These are often asymptomatic in the beginning, and narcotics or other drugs that may mask or exacerbate symptoms resulting from injuries in these regions should not be administered until the possibility of such trauma has been unequivocally excluded

General Care of the Patient

The welfare of the patient as a whole takes precedence over the treatment of any fracture Primarily, this involves (1) preservation of a properly functioning airway, (2) control of hemorrhage, and (3) prevention of shock

In an unconscious patient, maintenance of an adequate airway may require nothing more complicated than placing the patient in a semiprone position In this position aspiration of bronchial secretions and vomitus or dropping back of the tongue is least likely to occur If the tongue persistently drops back against the pharyngeal wall it must be pulled forward and, if necessary held forward by a suture or clamp through its tip

The patency of the airway may be preserved by the insertion of an oropharyngeal, nasopharyngeal or endotracheal tube which should be secured to the patient's head Where there is evidence of laryngeal obstruction emergency tracheotomy may be necessary This should be performed through a longitudinal incision just above the episternal notch Where a partially patent airway suggests the probable necessity of a subsequent tracheotomy this should be performed as soon as the indication arises through an elective transverse thyroid type of incision

Control of hemorrhage is the next most important consideration with respect to maintenance of the patient's circulating blood volume the prevention of shock, and management of the local wound

Considerable stress has been laid upon the use of a tourniquet by various civil groups and almost all nonprofessional people have come to rely and to insist upon this method of obtaining hemostasis in instances of acute hemorrhage Indeed, many professional people, including some physicians, have indicated that a tourniquet should be used to secure hemostasis in acute hemorrhage, with the provision that the tourniquet be loosened or removed periodically to prevent ischemia Both views are at complete variance with established surgical precepts A tourniquet, to be effective, must occlude all major and collateral arterial channels to the periphery and by design, therefore, its use produces total ischemia distal to the point of application

Intermittent release of a tourniquet, when once applied, does nothing more than permit the recurrence of the exsanguinating hemorrhage for the control of which the tourniquet was applied in the first place Blood flow to peripheral cells is essentially not increased by this procedure What little blood may get to the periphery usually passes through arteriovenous compensatory anastomoses, partially or entirely bypassing the peripheral capillary bed, is in part diluted by pooled venous blood containing metabolic products of hypoxic tissue, some of which are deleteriously vasoactive, and may be markedly slowed down owing to attempted passage through irreversibly damaged peripheral vascular channels

There appears little indication for the use of a tourniquet in the majority of acutely bleeding traumatic wounds In those few instances in which a tourniquet is indicated as a lifesaving procedure, it must not be released until definitive surgical intervention can be immediately corrective In this circumstance, the tourniquet should be placed as closely proximal to the wound as is possible to effect total distal ischemia and the physician, the patient, and the patient's family must be fully prepared for the eventual possible sacrifice of the limb Experience in two world wars, numerous armed conflicts, and civil disasters has amply demonstrated that the use of a tourniquet materially increases the amount of ultimate tissue destruction dramatically mitigates any subsequent attempts to preserve the local blood supply and adds little, if anything to what might be obtained more efficaciously by the use of other methods of hemostasis There is no question but that the loss of precious time involved in seeking and applying suitable tourniquets and the length of time for which they have been applied has caused considerably more loss of life and limb than would have been expended had the less dramatic but more proper method of compression been originally instituted Firm, constant, and uniformly applied pressure such as may be readily exerted by any voluminous sterile dressing is the least damaging to tissues most conveniently contrived, and in every way the most satisfactory means of attaining hemostasis in acute hemorrhage

A detailed account of the known and postulated mechanisms in the development of clinical shock is not germane to the present discussion It is, however important to recall that shock is primarily a manifestation of a decrease in effective circulating blood volume and that its most adequate method of prevention and treatment is by the restoration of the blood volume Clinically, the shock syndrome classically manifested by tachycardia hypotension, and cold hyperhydrosis of the skin does not usually appear until there has been a loss of about 30 per cent of the

effective circulating blood volume Such a patient presents a systolic blood pressure of 100 or less mm of mercury, a peripheral pulse of diminished volume intensity, and a tachycardia of at least 100 beats per minute

The amount of blood replacement necessary may be roughly gauged by the clinical response to a single unit, 500 ml of blood If the response is unsatisfactory, one or more additional units may have to be administered Where there is evidence or suspicion of continuing internal hemorrhage repeated transfusion is necessary until surgical control can be accomplished

A rough clinical method for gauging the volume of blood to be replaced in young adults was developed by British workers during World War II This method is based upon the hand volume equivalent of injured extremity tissues Abrasions, contusions, lacerations, ecchymoses, and other discolorations of the skin, marked swelling of the subcutaneous and other soft tissues, presence of broken bones, and loss of contractility of the muscles in the region of the extremity injury are the criteria used Small wounds, defined as those with less than one hand volume equivalent of injured tissue, are most frequently associated with blood losses of less than 10 per cent of the preinjury volume Medium wounds, those in which one to three hand volume equivalents of extremity tissue have been injured, are associated generally with a 20 to 40 per cent blood volume loss Large wounds, those with three to five hand volume equivalents of injured tissue, usually show a corresponding blood loss of about 40 per cent of the preinjury volume Very large wounds, in which more than five hand volume equivalents of tissue are injured, are usually associated with blood losses approximating 50 per cent of the total preinjury blood volume and, even when very promptly dealt with, are not infrequently associated with irreversible shock and death

Patients estimated to have sustained small wounds, less than one hand volume equivalent, require at most one unit of whole blood in the emergency period In medium-sized wounds, containing one to three hand volume equivalents of damaged tissue, the patient will require at least two or three units of whole blood, and in large wounds, with more than three hand volume equivalents of damaged tissue, five or more units of blood will usually have to be administered The minimum replacement requirements are about equal, therefore, to the hand volume equivalents of damaged tissue

Irrespective of these usual requirements, which are based upon wartime experiences with British troops, it is better to estimate the blood loss directly in every individual case Many laboratory methods have been devised to resolve this problem These range from weighing the sponges used to cover the wound to a number of different dye and isotope technics The hand volume technic is of value in the treatment of mass casualties and especially during the first half hour after injury In individual cases it is probably better to use more precise methods, based upon body weight and normal blood volume values

Normal blood volume in the average patient can be fairly well estimated from the fact that most individuals have a total blood volume equal to about 8 to 9 per cent of their body weight and a plasma volume of roughly 4 to 5 per cent of their body weight expressed in kilograms In the normal male, total blood volume

amounts to about 70 ml per kilogram of body weight, plasma volume equals about 39 ml per kilogram, and red cell mass about 30 ml per kilogram In most normal females, total blood volume is about 65 ml per kilogram, plasma volume about 37 ml per kilogram, and red cell mass about 27 ml per kilogram of body weight The normal hematocrit reading in males is about 43 per cent and about 42 per cent in females, but this may vary significantly in different geographical areas

Fairly accurate determination of a given patient s blood volume deficit, in terms of the normal, may be obtained by a determination of the total protein, hemoglobin concentration, or the hematocrit value of the peripheral blood Although the value of the figures thus obtained may be somewhat distorted by acute changes in body fluid dynamics and by the actual difference between large vessel and average body hematocrit readings, these discrepancies may be overlooked for routine clinical purposes

If it be assumed that a steady state exists at the time that the blood studies are performed and that this steady state is in equilibrium with the preinjury state, it is possible to estimate very rapidly the patient s actual blood volume and, hence, the requirements for restoration of normal blood volume by employing the dilution principle $C_0V_0 = C_1V_1$ *In this* C_0 *represents the normal hematocrit reading*, total protein, or hemoglobin concentration and V_0 the normal blood volume, plasma volume, or red cell mass C_1 and V_1 represent the corresponding parameters of the postinjury period The application of this method may be illustrated by the following hypothetical case

A 70 kg man was admitted to the emergency ward after an automobile accident in which he sustained an estimated four hand volume compound, comminuted fracture of the left femoral shaft The blood pressure was 90 systolic 50 diastolic The pulse was rapid and thready at 140 beats per minute The hematocrit reading was 30 per cent The patient was given 500 ml of blood plasma, was placed on shock blocks, and the fracture was splinted by a Thomas splint Despite the plasma the patient remained in shock and the question arose as to the nature and quantity of fluids to be administered

On the basis of the hand volume estimate of the local wound, this patient should have been given at least four units of whole blood On the basis of body weight, the normal estimated blood volume was about 4,900 ml (70 ml per kilogram body weight) Employing the dilution principle, and observed and normal hematocrit readings,

$$C_0V_0 = C_1V_1$$
$$(43) \times (4\,900) = (30) \times (V_1)$$

Whence,

$$V_1 = 7\,023 \text{ ml}$$

and the blood volume deficit equals $V_1 - V_0$,

$$V = 7\,023 - 4\,900 = 2\,123 \text{ ml}$$

Had this deficit been supplied by bank blood with an estimated hematocrit value of 40 per cent he should have received 850 ml of packed red cells and 1 270

ml of plasma. Since 500 ml of plasma had previously been administered, the remaining deficit consisted of approximately 850 ml of packed red cells and 770 ml of plasma.

In all situations of loss of effective circulating blood volume, the important consideration is to determine the volume of this loss rapidly and to replace it expeditiously. The most effective solution in replacement therapy is whole blood. Whole or lyophilized plasma, salt-poor human serum albumin, or synthetic plasma volume expanders are at best only of palliative value. In the final analysis there is only one substitute for blood, and that is blood itself.

Once emergency resuscitative methods have been instituted and the patient's general condition has been evaluated, attention may be directed to the care of the fracture itself. Before any attempt at treatment is undertaken, it is essential to determine the status of the circulation distal to the site of fracture. Impairment of the peripheral circulation may be due to actual loss of continuity of the arterial supply, to vasomotor spasm, to compression of the artery by an excessively large hematoma, or to compression by the fractured fragments. Appropriate measures to re-establish the peripheral circulation such as sympathetic ganglion blockade or release of the deep fascia must be instituted immediately. Where the malalignment at the fracture site is deemed to be the cause of the circulatory impairments, gentle traction may serve to avoid loss of the limb.

SPLINTING OF FRACTURES

Motion between the contiguous ends of a fractured bone gives rise to clinical signs and symptoms of a false point of motion and bone crepitus. Whether it be for didactic reasons or for the purpose of demonstrating the presence or degree of completeness of a dissolution of osseous continuity, such motion is to be strictly and categorically shunned. It imposes additional injury upon tissues already severely traumatized and further delays tissue anabolism and wound repair. It is painful, tends to precipitate or exacerbate shock, may lead to irreparable damage to neighboring vessels, nerves, and other soft tissues, predisposes nonunion by the interposition of soft tissues between the adjacent margins of the fracture, and to a greater or lesser degree disrupts the hematoma upon the integrity of which primary union of the fracture is predicated.

Recognition of these facts has thus led to the categorical injunction to "splint them where they lie" and, as a corollary, to transport the patient as expeditiously and with as little additional trauma as possible to a point where definitive therapy, both for the patient and for the fracture, may be instituted.

Splinting has several distinct advantages and virtually alone subserves most of the prime functions of first medical-aid care of fractures. It protects the fractured bone fragments and adjacent soft tissues from further injury, thus reducing the possibility of converting closed into open fractures. It prevents additional hemorrhage from both osseous and soft tissue vessels, reduces pain, lessens the tendency toward shock, obviates the accumulation of excessive amounts of blood, necrotic debris, and exudate, aids in minimizing the dissemination of contaminated or

frankly infected material, and permits normal healing processes to supervene upon the injury without untoward or unnecessary delay

Splinting can be performed practically painlessly at almost any time within the first half hour or so following fracture, the period of time during which the patient experiences numbness in the affected part (localized wound shock ') and, usually, an absence of reflex spasm of neighboring muscles (physiological splinting ') which at a later time, may materially increase the difficulty in reduction of the

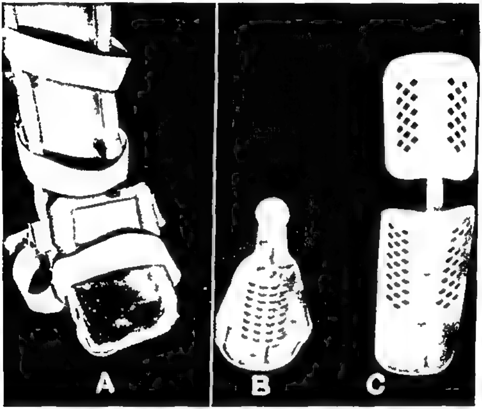


FIG 1 Prefabricated splints (*A*) Right angled splint lined with sponge rubber for immobilization of the leg and foot (*B*) Metallic splint for Colles fracture (*C*) Metallic right angled splint for im mobilization of the elbow region

fracture Gentle traction at the time of splinting is desirable Traction however is a double-edged sword and excessive traction either in duration or intensity may cause as much additional trauma as does the deliberate elicitation of bony crepitus

In long bone fractures emergency splinting can be readily effected by means of a branch cane board or any other material of adequate dimensions and sufficiently inelastic to prevent motion or axial malalignment Wherever possible however it is preferable to use splints that are specifically designed for use in the various ana tomical regions and that are usually available commercially (Fig 1)

Fractures of the femur are best splinted by means of a Thomas full ring splint (Fig 2) or the Hodgen half ring splint The ring should be adequately padded to prevent pain and abrasion from pressure against the ischium and pubis The ankle

is well padded so that traction may be applied without impairing the circulation of the foot The splint is slipped over the extremity without removing the patient's clothing and the traction straps are tied to the end of the splint to afford gentle traction at the fracture site (Fig 3) The limb is supported on a towel or canvas

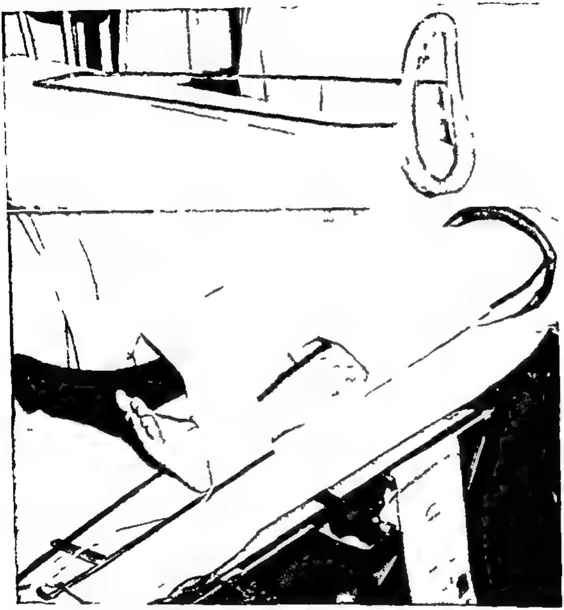


Fig 2 Thomas full ring splint The ring must be well padded to permit firm abutment against the ischium and the pubis Intrinsic traction may be obtained through a Spanish windlass attached to the distal end of the splint The leg should be supported on a towel or canvas pinned to the sides of the splint

pinned to the sides of the splint Where a Thomas splint is not available, temporary immobilization may be obtained by bandaging both limbs together

For fractures of the leg, a gutter splint or an ordinary pillow supported laterally and posteriorly by slats of wood and secured to the limb by simple gauze bandage a pillow and sides splint (Fig 4), or traction exerted through a Thomas splint afford efficient means of immobilization

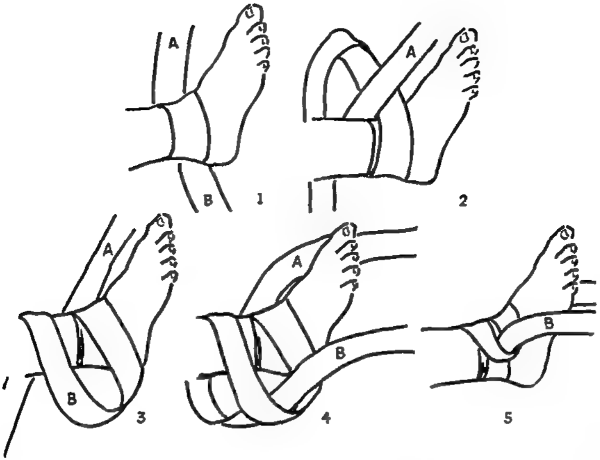


FIG 3 Collins hitch Details of a method whereby traction may be exerted on the lower extremity without impairing circulation The free ends of the Collins hitch are secured to the end of the Thomas splint and traction may be increased by twisting the ends of the hitch to make a Spanish windlass

FIG 4 Pillow and sides splint A pillow re enforced with slats of wood and fastened about the leg and foot by means of a gauze bandage makes a convenient and readily available splint for simple immobilization without traction of the foot and leg

In fractures of the upper extremity, traction can be applied through the Jones humerus splint (Fig 5) in the same manner as the Thomas splint is utilized for femoral fractures Fractures of the humeral shaft can also be immobilized in a simple coaptation splint (Figs 6 and 7) or by swathing against the thorax Fractures at both shoulder and elbow joints can be treated in the same manner Fracture of the forearm, wrist, or hand may be immobilized on a simple board splint (Fig 8) where more appropriate means are not available Emergency immobilization of

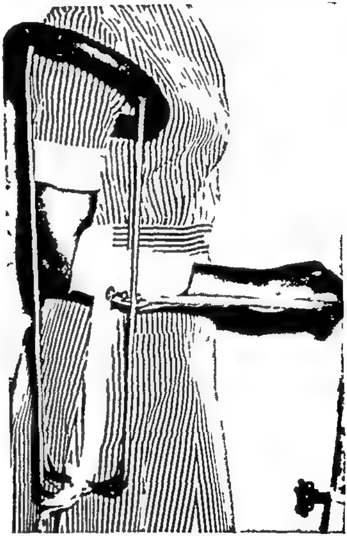


FIG 5 Jones humerus splint The splint is slipped over the arm and the ring is firmly fixed in the axilla The elbow is flexed to a right angle and the forearm is supported in the splint Gentle traction may be exerted by traction strips attached to the arm

pelvic girdle fractures is best afforded by swathing in a sheet or blanket Fractures of the clavicle can be temporarily immobilized by a sling that serves to remove the weight of the arm from the site of the fracture

Suspected fractures of the vertebral column present particular problems insofar as possible injury to the underlying spinal cord is concerned These patients should not be lifted onto any support but should rather be rolled very gently into position for transportation without any effort at correcting the malposition In suspected injuries of the thoracic or lumbar spine the patient may be transported in either the prone or supine position The prone position may present some difficulty as regards pulmonary ventilation This may be overcome by placing two longitudinally rolled blankets on either side of the chest under the shoulders

FIG 6 Coaptation splint This is made by facing one side of a wooden splint with adhesive tape and slitting the reverse side so that the splint can be curved to fit the surface of the rounded extremity

FIG 7 Coaptation splint applied for fracture of the humeral shaft Axial alignment is maintained by the application of the splint to the outer surface of the humerus where it is fixed by adhesive tape or a gauze bandage A simple bandage sling to the wrist has been added to support the hand wrist and forearm

In fractures of the cervical spine, the supine position must be employed This can be obtained by placing a small folded blanket between the shoulders so as to *permit slight hyperextension of the head*

As a general rule, there should be no attempts at correction of any fracture deformity at the scene of an injury, save insofar as the deformity may directly relate

FIG 8 Forearm and wrist board splint This is adequate for temporary immobilization of any fracture of the forearm wrist or hand The splint is padded and fixed to the forearm Extra padding should be added so as to preserve the hollow of the palm of the hand The thumb should be left free and in the position of opposition

to obvious interference with the major blood supply to a specific anatomical region, reduction should be deferred until such time as the patient can be seen at an institution where adequate supportive roentgenographic, anesthetic and therapeutic facilities are available Once a splint has been applied for temporary immobilization, it should not be removed for any purpose, including roentgenography, until definitive therapy is undertaken

CHAPTER 2

Axial Malalignments

The skeletal framework serves to maintain the configuration of the body and to afford attachment for its motivating musculature From a kinesiological point of view the bony structures act as a series of lever arms to which forces supplied by muscles are applied The joints act as fulcra about which the levers move in order to alter length for the purposeful application of motor power Such purposeful action is dependent upon the development of muscle patterns that are adapted to an established relationship between the bones and joints of the given individual

Fractures solutions of continuity in the bony framework disturb the configuration of the body and impair the function of the muscle motors that attach to the separate bones Any change in the relationship existing between these lever arms and fulcra implies not only a loss in the mechanical efficiency of the attached motors but alters the possibility of performing desired acts and determines the need for re-education to establish a new cerebral pattern fashioned to meet the altered physical conditions

Solution of continuity in a bone will occur whenever the force applied exceeds its ultimate strength which is, by definition greater than the measurable elastic limit of the bone The exact nature of the fracture that may result from any force is not predictable except in an academic manner In any given instance the resulting fracture will depend on at least two immeasurable variables first the ultimate strength of the bone which in turn is dependent upon the age of the bone its fluid content and its relative porosity among other factors and second the fracturing force which will depend upon the magnitude and rate of application of the force the direction in which it is applied and the area over which the impact occurs Except in a laboratory experiment these factors are indeterminable in any specific instance This accounts for the diversity of fracture lines seen in so called typical fractures as well as for the diversity of conditions that may follow an apparently similar injury Thus a fall on the outstretched hand may result in (1) Colles fracture (2) fracture of the carpal scaphoid (3) dislocations of the carpal semilunar, (4) Monteggia's fracture (5) fracture of the radial head, (6) dislocation

of the elbow, (7) supracondylar fracture of the humerus, (8) fracture of either humeral condyle, (9) fracture of the shaft of the humerus, (10) fracture of the surgical neck of the humerus, (11) dislocation of the shoulder, (12) fracture of the glenoid, and (13) fracture of the clavicle Similarly, a fall landing on the feet may lead to (1) a fracture of the os calcis, (2) fracture of the astragalus, (3) fracture of the ankle, (4) fracture of the tibial shaft, (5) fracture of the tibial condyles, (6) fracture of the femoral shaft, (7) fracture of the femoral neck, (8) fracture of the acetabulum, or (9) a fracture of the vertebral column

In the preroentgen era, elaboration of clinical methods was necessary for accurate diagnosis of a suspected fracture and for evaluation of the therapeutic result Since the development and the widespread use of the x-ray, the value of clinical examination has been largely supplanted by the proper roentgenographic diagnosis Indeed, failure to obtain adequate roentgenographic examinations both before and after undertaking the treatment of a fracture has come to be looked upon as neglectful of the patient's welfare

Routine roentgenography should be taken of all skeletal parts where injury is suspected It represents the only permanent record of actual injury, permits the recognition of often unsuspected fractures, and is the only clinical method by means of which minor avulsion fractures and sprain fractures may be differentiated with accuracy from the "sprains with which they have been and still are frequently confused The roentgenogram is of value not only in definitively establishing the presence of a fracture but, more importantly, in determining the exact nature of the displacement, if any exists, between the fractured fragments of the bone

Displacement of the fractured fragment is important in that it results in a change in the axial alignment of the bone A solution of continuity in bone may occur *without* gross *axial displacement,* as in subperiosteal fractures or in the milder degrees of so called torus and green-stick fractures or may occur *with* gross *axial displacement* of the distal portion of the fractured bone with respect to the proximal portion The former present little need for reduction, while the latter necessitate recognition of the deformity and realignment prior to immobilization

Axial malalignments in this latter type of fracture can be of four and only four types (1) lineal malalignments, (2) transpositional malalignments, (3) torsional malalignments, and (4) angulational malalignments (Fig 9)

Lineal Malalignments

A lineal axial malalignment is characterized by an actual, measurable change in the length of the fractured bone Increase in bone length may result from excessive traction or interposition of soft tissues between the contiguous margins of the fracture decrease may result from impaction of the fractured ends *one into* the other or from actual loss of osseous substance In all instances there is no alteration in the relationship between the axes of motion of the joint surfaces at either end of the fractured bone Irrespective of the direction of the line of fracture, the diameters of the fractured bone ends are mirror images of each other and the cortex

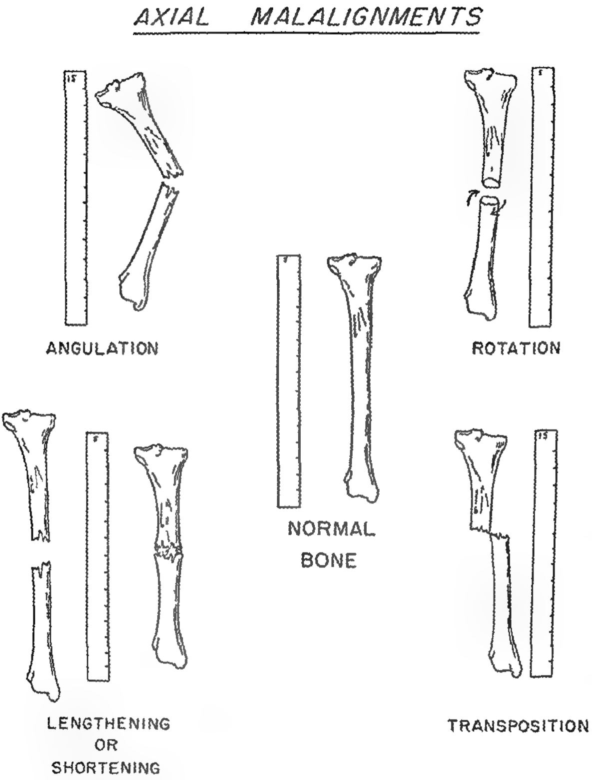


FIG 9 Axial malalignments Lineal malalignments are characterized by actual lengthening or shortening of the bone owing to distraction or impaction without any other change in anatomical relationship or axial alignment

Transpositional malalignments are characterized by parallel displacement of the axis of the distal fragment with a negligible but slight increase in the length of the affected bone and a corresponding change in the relationship of the articular surfaces at either end of the bone

Torsional malalignment results from rotation of the distal fragment with respect to

FIG 10 Lineal and transpositional malalignment Overriding of the distal fragment results from a parallel displacement characteristic of transposition and an upward displacement, characteristic of the lineal malalignment

of one fragment may be traced continuously into that of the other Roentgenographically, this type of axial malalignment is readily identifiable on ordinary anteroposterior and lateral x-ray films as a separation or telescoping of the bone fragments The anatomical axes of both fragments are collinear Overriding of the fragments with shortening of the bone is the result of a combined lineal and transpositional malalignment (Fig 10)

Transpositional Malalignments

A transpositional axial malalignment is characterized by a parallel displacement of the anatomical axis of the distal fragment As in the lineal type of malalignment there is no change in the cross-sectional diameter of the fractured bone ends and no angular alteration between the axes of motion of the joint surfaces at opposite ends of the bone There is however a definite shifting to one side or the other of

---

the proximal fragment There is no change in the length of the bone but there is an angular change between the axes of motion of the proximal and distal articular surfaces

Angulational malalignments are characterized by angulation of the axes of the proximal and distal portions of the bone There is a consequential shortening of the involved bone with a convergence of the planes of the opposite articular surfaces toward the concavity of the angulation

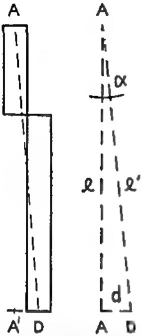


FIG 11 Transpositional malalignment Angle α is the measure of the axial inclination that has resulted from transposition of the central point of the distal fragment from A' to D In the right angled triangle $AA'D$ l' (AD) is obviously larger than l (AA') the original length of the bone

FIG 12 Transpositional malalignment Double step formation on opposite sides of the line of fracture in a femur previously ankylosed at the hip

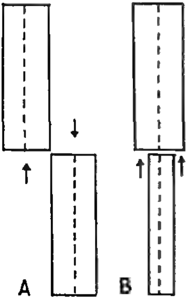


FIG 13 Step formation in transpositional and torsional malalignments In transpositional malalignments *A* the axis of the fragments are *parallel* and double step formation appears on *opposite* sides of the fracture line In torsional malalignments *B* when the axes of the fragments are *collinear* double step formation appears only on the *same side* of the fracture line

the distal articular surface of the fractured bone and, as a result, an inconsequential increase in the length of the bone (Fig 11) Roentgenographically, the axes of both fragments are no longer collinear but are parallel Because of this, a double step formation between the corresponding cortices of the fragments appears on *opposite* sides of the fracture line (Fig 12) In this respect, this malalignment differs from the type of step formation occasionally seen in torsional malalignments (Fig 13)

Torsional Malalignments

A torsional axial malalignment is characterized by an angular change between the axes of motion of the proximal and distal articular surfaces of a fractured bone

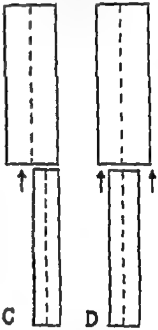


Fig 14 Step formation in torsional malalignments In torsional malalignments single step formation occurs when lateral cortex of the distal fragment is aligned with the lateral cortex of the proximal fragment There is slight displacement of the central axis but only a single step formation When the central axes of both fragments are collinear a double step formation on the same side of the fracture line is formed

The anatomical axes of the fragments may be either collinear, with the formation of a *double* step formation on the *same side* of the fracture line, or parallel with the formation of a *single step* (Fig 14)

This type of step formation results from the fact that long bones are normally either polygonal or ellipsoidal and that their cut surfaces present major and minor geometrical axes Twisting of a bone fragment with the application of a minor axis of one fragment to the major axis of the other results in a cross-sectional incongruence, in which the steps represent the difference in length between the major and minor axes of the opposing surfaces of the fractured fragments (Fig 15)

In acute fractures, the appearance on the roentgenogram of this cross-sectional incongruence presents positive evidence of the existence of a torsional malalignment which may be easily recognized in a roentgenogram taken only of the fractured region (Figs 16 and 17) Once healing has been initiated, however, and the appearance of step formation has become obliterated by excess callus formation, the presence of a torsional malalignment can only be diagnosed on a roentgenogram that shows *both* articular surfaces of the fractured bone Only in this way can torsion be differentiated from rotation

It is especially important to differentiate between torsion and rotation of the bone. Torsion involves a change within the bone, a rotation of one part of the bone with respect to the other part. Torsion implies an alteration in the axial alignment of the bone ends and necessarily involves a change in the function of the lever arm. Rotation, such as occurs in the motion of the radius around the ulna, involves merely a change in the relative position of the bone as a whole.

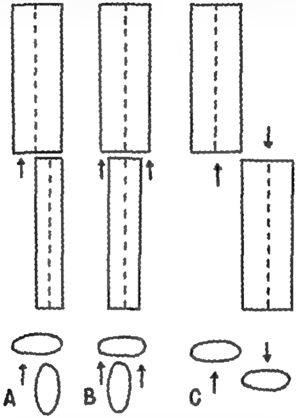


Fig. 15. Step formation and cross sectional incongruence. Cross sectional incongruence, the result of torsion, occurs when the minor axis of one fracture surface is applied to the major axis of the juxtaposed fracture surface. This can only arise as a consequence of the torsion of one fragment with respect to the other. Single step formation appears when the cortex of one fragment is in alignment with the cortex of the other fragment (*A*). Double step formation appears when the central axes of both fragments are collinear (*B*). This type of double step formation with the step on the same side of the fracture line is to be differentiated from the double step formation seen in transpositional malalignments where the step formation is on opposite sides of the fracture line (*C*).

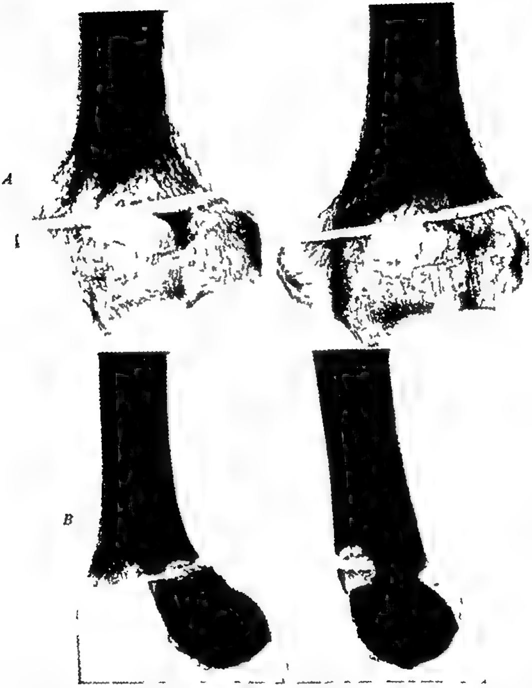


FIG 16 Cross sectional incongruence in torsional malalignments Torsion is frequently misapprehended as a transpositional malalignment as in supracondylar fractures here represented by a transverse osteotomy of the lower end of the humerus In the anteroposterior views *A* the distal fragment is either in good alignment or displaced laterally to a slight degree In the lateral views *B* however it is evident that there is no correspondence between the adjacent surfaces of the fractured fragments thus indicating the presence of torsional rather than a transpositional malalignment (Reproduced from Milch H *Osteotomy of the Long Bones* Charles C Thomas Springfield Ill 1947)

The forearm is particularly instructive and clinically important in this respect In the normal anteroposterior view of the completely supinated forearm, the coronoid process and the styloid process of the ulna lie in the axis of the shaft and are not readily visualized The radius, on the other hand, displays a medial projection of the bicipital tuberosity with a lateral projection of its styloid process In the lateral view the bones of the supinated forearm reverse their appearance The coronoid process of the ulna projects forward and the ulnar styloid backward The

FIG 17 Torsional malalignment Subtrochanteric fracture of the femur with external rotation of the distal fractured fragment The head and neck of the femur are seen in their normal positions but the lesser trochanter is abnormally prominent

previously noted projections of the radius however largely disappear since they now lie in the axis of the shaft

When *rotation* of the bone occurs as when the radius is in mid pronation the upper and lower end of the radius will present an appearance compatible with their degree of rotation (Fig 18) When *torsion* occurs the upper end of the bone will present an appearance that is normal for the particular roentgenographic exposure while the lower end will present an oblique or lateral appearance depending upon the existing degree of torsion (Figs 19 and 20)

ANGULATIONAL MALALIGNMENTS

An angulational axial malalignment is characterized by angulation of the anatomical axes of the fractured bone This may occur in any plane In the *coronal* plane angulations may occur either medially or laterally If the distal fragment is

FIG 18 Anteroposterior and lateral views of the normal forearm On the antero posterior view of the supinated forearm *A* the coronoid and styloid processes of the ulna are not visualized The bicipital tuberosity and the styloid process of the radius are on opposite sides of the bone On the lateral view of the supinated forearm *B* the coronoid and styloid processes of the ulna appear on opposite sides of the bone while the bicipital tuberosity and radial styloid process are not visualized On the an teroposterior view of the forearm in mid pronation *C* none of these four processes is clearly visualized On the lateral view *D* all four can be seen depending upon the de gree of rotation

The *forearm* is particularly instructive and clinically important in this respect. In the normal anteroposterior view of the completely supinated forearm, the coronoid process and the styloid process of the ulna lie in the axis of the shaft and are not readily visualized. The radius, on the other hand, displays a medial projection of the bicipital tuberosity with a lateral projection of its styloid process. In the lateral view, the bones of the supinated forearm reverse their appearance. The coronoid process of the ulna projects forward and the ulnar styloid backward. The

FIG. 17. Torsional malalignment. Subtrochanteric fracture of the femur with external rotation of the distal fractured fragment. The head and neck of the femur are seen in their normal positions, but the lesser trochanter is abnormally prominent.

previously noted projections of the radius, however, largely disappear since they now lie in the axis of the shaft.

When *rotation* of the bone occurs, as when the radius is in mid pronation, the upper and lower end of the radius will present an appearance compatible with their degree of rotation (Fig. 18). When *torsion* occurs, the upper end of the bone will present an appearance that is normal for the particular roentgenographic exposure, while the lower end will present an oblique or lateral appearance, depending upon the existing degree of torsion (Figs. 19 and 20).

ANGULATIONAL MALALIGNMENTS

An angulational axial malalignment is characterized by angulation of the anatomical axes of the fractured bone. This may occur in any plane. In the *coronal* plane, angulations may occur either medially or laterally. If the distal fragment is

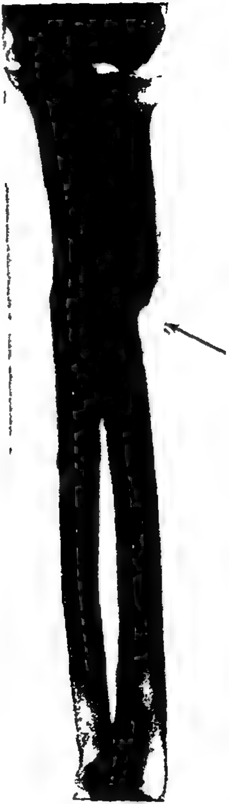


FIG 20 Torsional malalignment in a healed fracture of the forearm The ulna has been properly aligned Step formation is seen in the radius but can be differentiated from that of a transpositional malalignment only by the fact that the upper end of the radius presents its normal anteroposterior view while the lower end presents its normal lateral appearance

angulated medially a varus or adduction deformity occurs, with the apex of the angle of deformity directed laterally (Fig 21) If the distal fragment is angulated laterally, a valgus or abduction deformity occurs with the apex of the angle of deformity directed medially (Fig 22) In the *sagittal* plane, angulations may occur either anteriorly or posteriorly If the distal fragment is angulated anteriorly, a

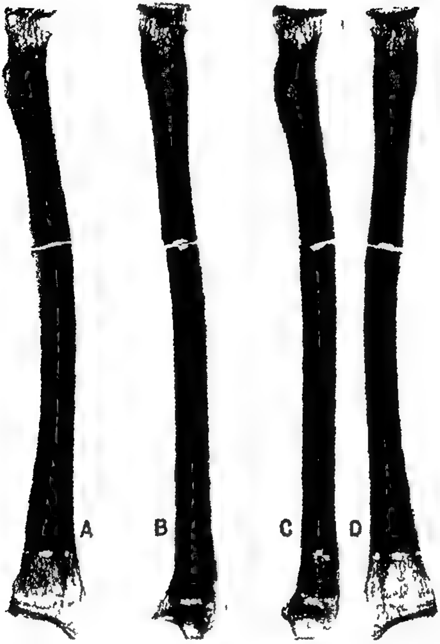


FIG 19 Rotation and torsion of the radius In *A* the normal anteroposterior view of the radius discloses both the styloid process and the bicipital tuberosity on opposite sides of the bone In *B* the normal lateral appearance of the radius is similar to that seen on the normal anteroposterior view of the radius rotated into mid pronation Neither the styloid process nor the bicipital tuberosity is visualized In *C* the bone has been transected and the distal fragment rotated ninety degrees The upper end of the radius presents its normal anteroposterior view while the lower end presents the normal lateral view In *D* the upper end of the radius presents its normal lateral view while the lower end presents the normal postero anterior view indicative of ninety degrees of rotation of the distal fragment The rotation of the distal fragment in *C* and *D* represents the torsional malalignment

Fig 24 Parallax phenomenon Two views of a fractured forearm taken sequentially with change only in the direction of the central x ray beam The forearm was immobilized in a plaster of Paris cast and the apparent change in alignment at the fracture site is a projective illusion

FIG 21 Angulational malalignment Coxa vara deformity due to adduction frac ture of the neck of the femur The distal fragment consisting of the entire femoral shaft is angulated medially The apex of the angular deformity is directed laterally

FIG 22 Angulational mal alignment There is an abduction fracture of the shaft of the femur The distal fragment is angulated laterally the apex of the angle of the deformity is directed medially

FIG 23 Angulational malalignment There is an extension type of fracture of the lower end of the radius with posterior angulation of the distal fragment The apex of the angle of deformity is directed an teriorly

FIG 24 Parallax phenomenon Two views of a fractured forearm taken sequentially with change only in the direction of the central x ray beam The forearm was immobilized in a plaster of Paris cast and the apparent change in alignment at the fracture site is a projective illusion

FIG 25 Parallax phenomenon Displacement of the projection of a probe fixed to the outer surface of a plaster cast discloses immediately that the x ray film was taken in different positions and that any apparent change in alignment may be a projective illusion A change in axial alignment without a change in the position of the projection of the probe would be significant Left view anteroposterior Right a lateral view

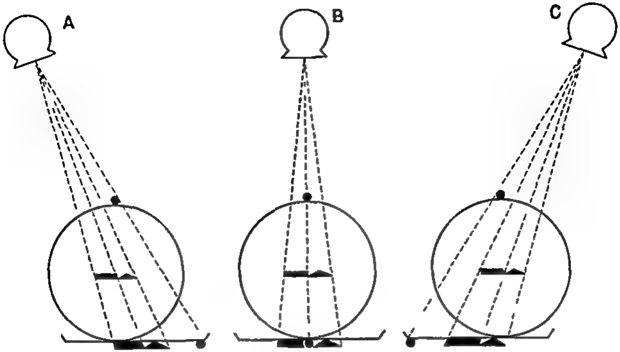


FIG 26 Parallax phenomenon The large circular outline represents the plaster mold immobilizing a triangular and rectangular bone The solid circle on the surface of the plaster mold represents the metallic marker or probe In *A* and *C*, the x ray tube has been displaced and the projection of the metallic marker has been displaced to opposite sides In *B* the marker and its projection lie in the central x ray beam (Reproduced from Milch H *Osteotomy of the Long Bones* Charles C Thomas, Springfield Ill 1947)

flexion type of deformity develops if the distal fragment is angulated posteriorly, an extension type of deformity develops (Fig 23)

A definite measurable shortening of the bone occurs in all angulational axial malalignments As a consequence of this, it is imperative to correct angulational axial malalignments at the apex of the angle of deformity Correction at any other point necessarily results in additional shortening of the bone Furthermore, the change in the anatomical axes of the two fragments that characterize angulational malalignments imposes a corresponding change in the relationship of the axes of motion of the joints at the opposite ends of the involved bone

While angulational malalignments are usually readily recognized on segmental x-ray views of the fracture area, it must not be forgotten that the roentgenogram is only a projective phenomenon Since angles are not projective phenomena, particular care must be given to the roentgenographic evaluation of the angular deformities Rotation of the limb as a whole an alteration in the direction of the central x ray beam or a change in the position of the film casette in sequential roentgenograms may not infrequently lead to erroneous conclusions as to possible changes in the degree of angulation of the fragments (Fig 24) Such conclusions may be of considerable significance not only in their surgical indications but also with respect to their medicolegal implications

The proper care of any fracture requires the taking of frequent checkup x-ray

FIG 25 Parallax phenomenon Displacement of the projection of a probe fixed to the outer surface of a plaster cast discloses immediately that the x ray film was taken in different positions and that any apparent change in alignment may be a projective illusion A change in axial alignment without a change in the position of the projection of the probe would be significant Left view, anteroposterior Right a lateral view

CHAPTER 3

Epiphyseal Injuries

Epiphyseal Separations

Epiphyseal separations must be considered as special types of fracture They are, obviously, seen only in youngsters before closure of the epiphyseal line has occurred and are characterized by the fact that the fracture line follows the course of the growth zone (Figs 27 and 28) Occasionally it is difficult to differentiate between variations in the normal process of ossification and frankly pathological conditions (Fig 29) It is, therefore, extremely important to bear clearly in mind the usual time of appearance and closure of the various epiphyses (Fig 30)

Because of their inherent growth potentialities, separation of epiphyses must be reduced as soon and as accurately as possible Failure to secure precise anatomical reduction, however, does not in itself lead to impairment in growth Simple shearing off of the epiphyseal plate, with the production of a transpositional or torsional malalignment, does not constantly result in interference with normal growth Angulational malalignments invariably result in an axial change, while lineal compressions almost always result in early closure of the epiphyseal plate with marked loss in the ultimate growth of the bone

If the entire epiphysis is compressed synchondrosis results with loss of normal growth at this epiphyseal line The consequence is a shortening of the bone as a whole (Fig 31) Where only a portion of the epiphyseal plate has been injured however, as in fractures that traverse the epiphyseal line perpendicularly, only that portion of the plate which has been injured may undergo synchondrosis while normal growth will occur in the rest of the growing zone (Fig 32) The result of this is an angulational deformity that is amenable to correction only by repeated osteotomy until the epiphysis has closed normally Surgical obliteration or stapling of the unaffected part of the epiphyseal plate is to be disparaged as leading to permanent loss in length of the affected bone

films It is important however, to be certain that the fracture site is exposed to both the x ray beam and the film casette in precisely identical positions at each examination *The only means of obtaining absolute assurance of identical exposures* is by incorporating a radioopaque material such as a metal wire or probe, on the outer surface of the immobilizing cast (Fig 25) By the physical principle of parallax, any shifting of the projection of the wire or probe on the x-ray film as compared with the original films is positive evidence that there has been a change in the relationship between the x-ray tube, the fracture and the film casette (Fig 26) Any conclusion as to change in angular relationship of the bone fragments is completely invalidated under these circumstances

Stripped of all details the essence of fracture treatment is the careful analysis of the deformity of each fracture into one or more types of axial malalignment, the correction of each of these malalignments and retention of the corrected position until healing has occurred (Table 1)

TABLE 1—SUMMARY OF AXIAL MALALIGNMENTS

	Lineal	*Transpositional*	*Torsional*		*Angulational*
Effective bone length	Increased or decreased	Negligible increase	Unchanged		Decreased
Cross sectional incongruence	Absent	Absent	Present		Absent (inapplicable)
Anatomical axis	Collinear	Parallel	Parallel	Collinear	Angulated
Mechanical axis	Unchanged	Changed	Negligible change	Unchanged	Changed
Type of step formation	None	Double (opposite sides)	Single (same side)	Double (same side)	None

CHAPTER 3

Epiphyseal Injuries

EPIPHYSEAL SEPARATIONS

Epiphyseal separations must be considered as special types of fracture They are, obviously, seen only in youngsters before closure of the epiphyseal line has occurred and are characterized by the fact that the fracture line follows the course of the growth zone (Figs 27 and 28) Occasionally it is difficult to differentiate between variations in the normal process of ossification and frankly pathological conditions (Fig 29) It is therefore, extremely important to bear clearly in mind the usual time of appearance and closure of the various epiphyses (Fig 30)

Because of their inherent growth potentialities, separation of epiphyses must be reduced as soon and as accurately as possible Failure to secure precise anatomical reduction, however, does not in itself lead to impairment in growth Simple shearing off of the epiphyseal plate, with the production of a transpositional or torsional malalignment does not constantly result in interference with normal growth Angulational malalignments invariably result in an axial change, while lineal compressions almost always result in early closure of the epiphyseal plate with marked loss in the ultimate growth of the bone

If the entire epiphysis is compressed synchondrosis results with loss of normal growth at this epiphyseal line The consequence is a shortening of the bone as a whole (Fig 31) Where only a portion of the epiphyseal plate has been injured however as in fractures that traverse the epiphyseal line perpendicularly only that portion of the plate which has been injured may undergo synchondrosis while normal growth will occur in the rest of the growing zone (Fig 32) The result of this is an angulational deformity that is amenable to correction only by repeated osteotomy until the epiphysis has closed normally Surgical obliteration or stapling of the unaffected part of the epiphyseal plate is to be disparaged as leading to permanent loss in length of the affected bone

FIG 27 Epiphyseal separation of the upper end of the humerus The capital humeral epiphysis has been sheared off from the shaft of the bone The upper end of the shaft articulates with the glenoid while the capital epiphysis is displaced laterally

FIG 28 Upper femoral epiphysiolysis The neck and shaft of the femur have rotated externally The capital femoral epiphysis still articulates with the acetabulum There is some upward displacement of the femoral

FIG 29 Bipartite epiphysis in a normal shoulder Both normal halves of the capital humeral epiphysis are seen and simulate a fracture The medial larger half usually appears at the age of seven weeks The lateral half does not appear until the age of two years but usually unites with the humeral shaft long before the medial half

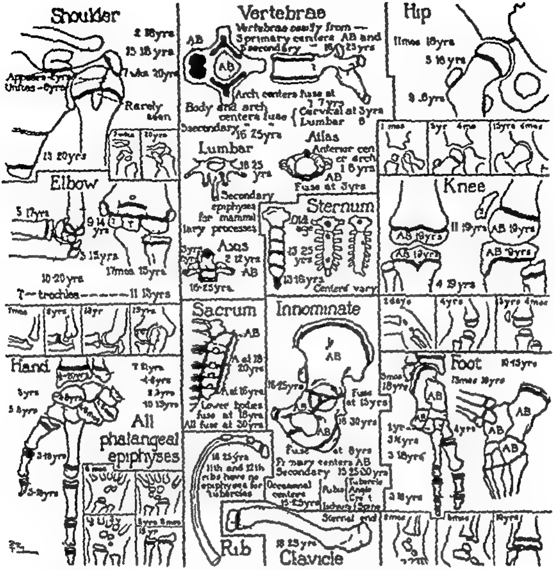


FIG 30 Normal development of centers of ossification for the epiphyses and their time of closure (Reproduced from Camp J D and Cilley E I L Bone Ossification Chart *Am J Roentgenol* 26 905, 1931)

Fig 27 Epiphyseal separation of the upper end of the humerus The capital humeral epiphysis has been sheared off from the shaft of the bone The upper end of the shaft articulates with the glenoid while the capital epiphysis is displaced laterally

Fig 28 Upper femoral epiphysiolysis The neck and shaft of the femur have rotated externally The capital femoral epiphysis still articulates with the acetabulum There is some upward displacement of the femoral

Fig 29 Bipartite epiphysis in a normal shoulder Both normal halves of the capital humeral epiphysis are seen and simulate a fracture The medial larger half usually appears at the age of seven weeks The lateral half does not appear until the age of two years but usually unites with the humeral shaft long before the medial half

Epiphyseal Pseudarthrosis

Normally, epiphyseal separations heal by the deposition of periosteal and parosteal callus, while the line of fracture itself is obliterated in the normal process of endochondral bone growth. Pseudarthrosis formation almost never occurs except in those cases in which the small epiphyseal fragment is fixed to the adjacent joint by ankylosis. In such event, immobilization must be continued until complete healing has occurred. Early motion will lead to the transfer of mobility from the normal region of the ankylosed joint to the site of epiphyseal separation. This is seen in instances where an effort has been made to fuse a joint before closure of the adjacent epiphyseal line. In many cases it accounts for the reported failure of arthrodesing operations, as in tuberculosis of the hip, where motion at the epiphyseal plate has been misapprehended as failure of surgical fusion (Fig. 33).

Fig. 33. Epiphyseal pseudarthrosis at the upper end of the femur. Following arthrodesis of the hip, excessive mobility which was attributed to failure of fusion was noted. This was subsequently shown to be due to the development of a pseudarthrosis at the level of the widened epiphyseal space. Complete union occurred following simple immobilization in a plaster of Paris spica. (Reproduced from Milch, H.: Epiphyseal pseudarthrosis. *J. Bone & Joint Surg. 24*:653, 1942.)

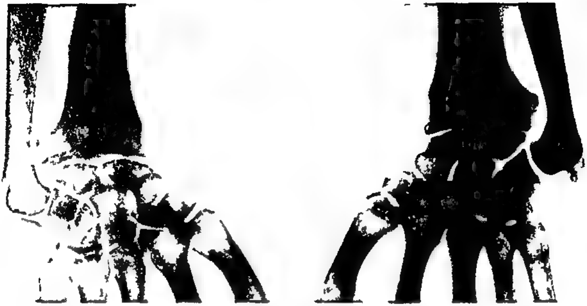


FIG 31 Bilateral synchondrosis of the lower radial epiphysis Following a fall on the outstretched hands the epiphyseal plate was compressed radial growth was impaired with subsequent overgrowth of the ulna (Reproduced from Milch H Bilateral post traumatic ulno cuneiform articulation *Am J Radiology 61* 80 1949)

FIG 32 Synchondrosis of the lower tibial epiphysis Following a longitudinal fracture of the medial malleolus and the medial half of the lower tibial epiphysis growth in the medial half of the epiphysis was retarded with subsequent relative over growth of the fibula and the development of a varus deformity

The total amount of bone tissue lost as a result of injury is a function not only of the direct effects of mechanical violence to the bone cells, but also of the effects of impairment of the osseous circulation that results from the fracture. The shafts of the long bones are supplied through five different circulations: (1) an anastomosing plexus of periosteal vessels, generally longitudinally disposed along the anatomical axis of the bone, interconnected by Volkmann's canal twigs, which join the periosteal systems more or less transversely, (2) an outer circumferential layer of transversely disposed vessels lying within the outer cortex of the bone, (3)

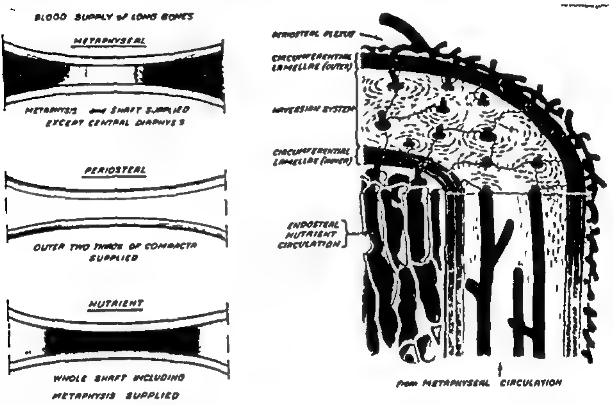


FIG 34 Blood supply of the long bones (Reproduced from Starr, K. W.: *Delayed Union in Fractures of the Long Bones*. C. V. Mosby Co., St. Louis, 1947.)

the Haversian systems, longitudinally arranged within the cortex, (4) an inner circumferential layer lying just beneath the inner layers of the cortex, and (5) the endosteal nutrient and metaphyseal vessels that ramify both within the narrow and the inner third of the cortex (Fig. 34). When a bone is broken, the pattern of its blood supply is disrupted at the line of fracture, but the area of resulting ischemic necrosis is less than might be expected. Since the periosteal plexus supplies the outer one half to two thirds of the cortex, while the main supply of the shaft is derived from ramifications of the metaphyseal and nutrient artery plexuses, an adequate collateral circulation is usually present in each fractured fragment so that only a few millimeters of the bone on either side of the fracture line actually undergo necrosis. Tissue fluid reaches bone cells by diffusion through the tiny canaliculi radiating out from each lacuna in which the bone cells are entrapped.

CHAPTER 4

Healing of Fractures

Despite a rather considerable literature on the anatomical structure of normal and transplanted bone, little is known about the response of bone to trauma or the intimate mechanisms of its repair. Only slight attention has been directed to some of the gross in vitro properties of intact bone and, although something has been learned about the chemical anatomy of normal bone mineral, much remains, biologically considered, to be discovered.

While the actual physiology of bone injury and bone repair remains largely unelucidated, much worthwhile information has been obtained at the histological level. At this level, it is convenient to think of the sequence of events following bone injury, such as a fracture, as presenting five more or less distinct phases: (1) immediate effects of direct trauma, (2) clotting of the fracture hematoma and reactive inflammation, (3) formation of the fibrous callus, (4) formation of the bony callus, and (5) reconstruction of bone. All these phases must be considered in the light of the fact that, strictly speaking, bone never regenerates. It is rather *replaced* in a process that is continuous from practically the very moment of injury. As in other injuries, it is characterized by a reactive inflammatory phase and a phase of revascularization and connective tissue repair. Repair in bone differs from the repair of defects in other tissues, however, in that the reparative matrix bridging the defect in bone tissue must subsequently undergo mineralization and, at a later time, complete reorganization into normal bone.

Immediate Effects of Trauma

When a fracture occurs as a consequence of the impact of an injuring force, a certain amount of bone as well as adjacent soft tissue is directly destroyed. In general, the direct effects of the injury will depend upon the physical nature and properties of the impacting force as well as the character of the tissue upon which the force is expended. The tissues directly subject to the force disintegrate and undergo various degenerative phenomena. It is the neighboring tissues not directly subject to the adverse effects of the injuring force that survive and play the dominant roles in the immediate reparative processes.

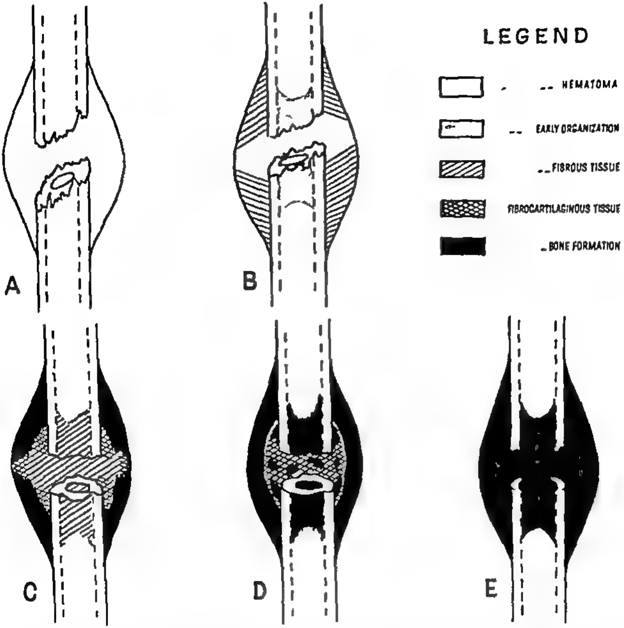


FIG 35 Phases of fracture healing The hematoma *A* is gradually invaded by fibrous connective tissue that begins in the subperiosteal and intramedullary portions of the hematoma, *B* Subsequently primary bone develops in the periosteal callus while fibrocartilaginous callus appears in the region of the parosteal callus surrounding the fractured bone ends *C* Following this new bone formation occurs in the region of the endosteal and later the parosteal callus *D* while fibrous and fibrocartilaginous callus persists in the interfragmentary portion of the callus Finally bony callus formation proceeds until all regions of the callus are united to form the primary bony callus *E* In general the sequence of events is the development of fibrous callus followed by bony callus in the subperiosteal region then the endosteal region later the parosteal region and finally in the interfragmentary portion of the original fracture hematoma A fibrocartilaginous phase may appear and persist in the region of the parosteal callus

The great majority of these bone cells are not more than 0 1 mm , and only a few are as much as 0 20 to 0 25 mm away from a capillary Only those cells from 0 1 to 0 25 mm away from a capillary bed on either side of the fracture line are likely to undergo ischemic necrosis

Immediately after the injury, and as a result of the disruption of the blood supply to the bone and neighboring soft tissues, there is an outpouring of blood that leads to the formation of a hematoma between and around the fractured bone ends The shape and extent of the hematoma are in large part dependent upon the integrity of the periosteum In the young where the periosteum of the long bones is thick, strong, highly elastic, and firmly attached at the epiphyseal lines, the periosteum is more likely to strip than to tear and, as a consequence a spindle-shaped hematoma is formed, thickest at the level of the fracture and tapering at either end In adults, where the periosteum is less elastic and hence tears more readily, the hematoma is apt to be more diffuse The intramedullary portion of the hematoma in both children and adults will depend to a large extent upon the location of the fracture In the tubular portion of the bone it will extend for a variable distance up and down the narrow cavity, whereas in the spongy portion of the bone as in the small flat membrane bones the hematoma will be diffused throughout the bone

Clotting of the Hematoma and Reactive Inflammation

Hemorrhage into and around the site of the fracture continues until the pressure within the hematoma cavity equals or exceeds the hydrostatic pressure within the ruptured vessels that at the same time undergo reactive vasoconstriction retraction of the elastic tissues within their walls, and thrombus formation Between twelve and twenty four hours after fracture blood clot formation may be seen beginning about the periphery of the hematoma and gradually progressing centripetally At the end of the first day after fracture the interfragmentary hematoma is usually entirely coagulated Occasionally, the central portion of the hematoma may not completely clot and it is sometimes possible to find a clear serosanguineous fluid at the central portion of the hematoma even several weeks after fracture (Fig 35*A*)

Within twenty four to thirty-six hours after injury the first histological signs of repair phenomena become apparent There is evidence of autolysis and absorption of the dead or dying bone and degenerating soft tissues within the hematoma With the formation of the hematoma, inflammatory changes are initiated in both the neighboring bony and soft tissues The primary response is vascular, leading to the characteristic cardinal signs of inflammation but this is closely followed by the typical cellular response that completes the pattern of inflammation

These processes dominate the histological pattern of the first twenty-four to thirty-six hours of the postinjury period in closed fractures When a wound in the overlying skin communicates with the fracture site so that the fracture is frankly contaminated and potentially infected essentially the same sequence of events takes place though the process is complicated by the effects of microbial multiplication and additional tissue destruction

FORMATION OF PRIMARY BONY CALLUS

When the scaffolding provided by the fibrous-fibrocartilaginous callus has been completed, two to three weeks following fracture, the remainder of the process of bone repair is characterized by replacement of this callus For purposes of description it is convenient to divide the primary bony callus into several different components on the basis of their usual time and site of appearance, as well as the nature of the bony replacement that takes place The first portion of the bony callus to appear is almost entirely *intramembranous* in origin It appears first as the periosteal callus and later as the endosteal callus (Fig 35*D*)

The intramembranous portion of the bony callus is characterized by the development of an ' osteogenetic front ' consisting of primitive marrow osteoblasts and new blood vessels

The osteogenic front develops first in the periosteal callus and proceeds toward the region of the parosteal callus As it advances into the fibrous callus, absorption of old acellular bone occurs and new bone is deposited on the old trabecular surfaces The trabeculae in the periosteal callus are more or less parallel to one another and oblique to the anatomical axis of the bone Subsequently, the intramedullary portion of the bony callus is formed by means of irregularly arranged trabeculae of new bone that act to seal off the medullary cavity from the interfragmentary portion of the callus

While the osteogenic front is advancing fibrocartilage and occasionally even hyaline cartilage differentiate in the region of the parosteal callus Depending in large part upon the degree of motion or mechanical stress that exists between the fragments bone formation in this region is largely of the *endochondral* type True endochondral bone formation is usually deferred, however, until the intramembranous bone formation in the periosteal callus approaches the cartilage of the parosteal callus Complete endochondral ossification of parosteal cartilaginous callus takes place, but cartilaginous islands or dense cartilage bands may persist even after invasion by the osteogenic front The occurrence of cartilage is more common in the parosteal callus, which forms first and unites the outer cortical surfaces of the two fractured fragments, than in the interfragmentary portion that forms last

Ossification of the interfragmentary portion of the fibrous callus begins only when other portions of the bony callus are well developed This portion of the callus is largely intramembranous in nature although scattered islands of fibrocartilage or hyaline cartilage which may have been formed undergo endochondral ossification

Absorption of the necrotic fracture fragments continues until late in the healing sequence and primary bony callus formation is not completed until all these processes have terminated The end result, the primary bony callus, is usually completed about five to seven weeks after the injury has been sustained Mineralization is however still incomplete at this time The bony callus still casts a relatively faint shadow on the roentgenogram and on section, can easily be cut by the scalpel

FORMATION OF THE FIBROUS CALLUS

The inflammatory and exudative changes characteristic of the first several hours following fracture become more prominent after twenty-four to forty-eight hours There is considerable histological evidence of phagocytosis and removal of cellular debris Within the bone itself, the much debated osteoclasts, other foreign body giant cells, and the cells characteristic of chronic inflammation appear Although some osteoclasts may be seen in the region of the interfragmentary hematoma, the osteoclastic cellular response is most pronounced along, and often confined to, the inner walls of the shaft of the bone at a considerable distance from the actual line of fracture

At the same time, organization of the hematoma and formation of granulation tissue begin Blood vessels proliferate and invade the margins of the blood clot Surrounding connective tissue cells along with the proliferation of new capillaries follow closely, and usually at the end of the first week following fracture the hematoma has become largely replaced by slowly maturing fibrous connective tissue (Fig 35*B*) Admixed within the connective tissue there is often some fibrocartilaginous and hyaline cartilaginous tissue In the interstices of this tissue, wandering cells, histiocytes, and adventitial cells derived both from the undifferentiated mesenchyme and from cells normally found close to small arterioles and capillaries are seen Bars of osteoid tissue, which may be seen as early as seventy two hours after fracture are now well developed

There is considerable discussion among histologists as to the actual origin of the cartilaginous elements found in the organized hematoma Some believe that cartilage appears as a consequence of metaplasia of normally undifferentiated pleuripotential connective tissue cells Others are of the opinion that a process of induction or true metamorphosis occurs At any rate, between seven and ten days following fracture fibrous and fibrocartilaginous callus has formed to replace the original hematoma and to join the contiguous portions of the fractured bone This fibrous callus like the hematoma tends to be spindle-shaped is broadest at the center and narrowest at the distal extremities It extends for a considerable distance along the two large fragments filling the cleft between the fragments and sealing the marrow cavity of each fragment more or less completely by two concentric spindles of reparative tissue

Signs of inflammation persist in the tissue at this time but, in the interim, have come to play a histologically less significant role Chronic inflammatory cells predominate throughout the continuing healing process Maximal fibrous and fibrocartilaginous callus formation occurs at approximately two to three weeks subsequent to the fracture At this time there is marked evidence of osteoid tissue deposition throughout the callus (Fig 35*C*) Osteoid that had been deposited as early as seventy-two hours after fracture is almost immediately mineralized Two to three weeks after injury narrow osteoid borders may be seen on most of the surviving and newly proliferating bony trabeculae though formation of the bony callus is not completed until several weeks thereafter

Fig 36 Delayed union in multiple fractures of the leg Normal development of the callus has occurred in the fibular fractures as well as in the lower of the two fractures of the tibia In the upper tibial fracture however there is delayed union but no evidence of nonunion

Fig 37 Nonunion of tibial fracture Longitudinal section of bone removed from the tibia in Fig 36 after nonunion had developed at the site of the upper tibial fracture The bony callus in the lower fracture is complete In the upper fracture the interfragmentary portion of the callus does not exist and the union between the periosteal and parosteal callus is cartilaginous A bone graft was inserted

Complete mineralization of the primary callus does not occur until two to three weeks later (Fig 35*E*)

Formation of the Secondary Bony Callus

Reorganization of the irregularly arranged, coarse bony trabeculae characterizes the formation of the secondary bony callus At about six to eight weeks after fracture, when the gap between the fragments has been closed by means of the primary bony callus, the bony trabeculae closest to the line of fracture gradually increase in thickness by deposition of concentric lamellae of bone Instead of actively growing polygonal shaped osteoblasts that lie immediately beneath the newly deposited bone trabeculae in the outer portions of the callus, the older bony trabeculae in the innermost parts of the callus become lined with spindle shaped osteoblasts and osteocytes The coarse fibrillar bone of the primary bony callus is gradually resorbed and replaced by means of mature lamellated compact bone with discrete Haversian systems and the medullary cavity is gradually re established Completion of the process of reorganization and reconstruction of the normal architecture of the bone may take as long as one or two years

All these processes of normal fracture healing depend upon the formation of an adequate interfragmentary hematoma, the maintenance of end to end contact between the fractured fragments and relative immobility of the fragments during the process of healing Early motion between the fragments leads to fracture of the hematoma and impairment of the process of fibrous callus formation This, in turn, leads to excessive fibrous tissue formation and to the development of fibrocartilage which may in turn eventuate in delayed union or nonunion

Delayed Union and Nonunion of Fractures

While the time schedule for the initiation of the various stages in bone repair coincides approximately with that noted above, there is no absolute period of time within which normal healing may properly be said to occur Generally speaking healing will occur earlier in the bones of children than in those of adults will occur sooner in spongy bone than in compact bone, and will occur more readily in the small bones, such as the finger than in the long bones, such as the femur

The processes of healing are essentially the same in both normal and delayed bone repair Certain bones such as the lower third of the tibia the carpal scaphoid the femoral neck mid portion of the humerus and the clavicle seem to manifest a predilection for delayed healing Many different causes have been advanced to explain this tendency These include inadequate blood supply resulting from injury of the surrounding soft parts with inadequate formation of an interfragmentary *hematoma, excessive traction with loss of bony contact between the fractured ends* and inadequate immobilization Roentgenographically the fracture site appears indolent and there is a lack of the normal progress of deposition of radiopaque material across the fracture line The fractured ends however are still irregular hazy and show no evidence of excessive sclerosis (Figs 36 and 37) Completely

to interfere with the hematoma and the apposition of the bone ends Infection usually tends actually to destroy the hematoma, but in some cases it may later establish an involucrum and thus restore the continuity of the bone

True nonunion is diagnosed on the basis of both its roentgenographic appearance and the persistence of a false point of motion The fractured ends appear rounded, are well defined, and are usually excessively sclerotic in appearance (Fig 38) They may be united by a fibrous sheath or a true cavity filled with synovial fluid may exist between the ends of the bone, so that a true joint is formed In such instances, any possibility of further healing cannot be contemplated unless the conditions of an acute fracture are re-established This usually involves operative intervention, which may be accomplished by (1) drilling of the bone ends, (2) excision of the fibrous callus and unsealing of the medullary cavity, or (3) bone grafting The placing of a bone graft satisfies all these conditions and has the additional advantage of affording a relatively firm means of internal fixation

Fig 38 Nonunion of the tibia The adjacent surfaces of the fractured fragments have been partially absorbed and there is actual loss of bony substance between the fractured ends The bone ends are sclerotic and their medullary canals are sealed off The fibula has markedly hypertrophied and has assumed part of the function of support previously performed by the tibia

normal union is still possible in such cases provided the disturbing factors are eliminated Immobilization must be maintained and, in lower extremity fractures distraction of the bone fragment can be overcome and callus formation stimulated by weight bearing

Nonunion may result from excessive prolongation of the period of healing but may also be due to interposition of soft tissue, infection interference with the mechanism of blood clotting or other unknown factors such as operate in the cases of congenital pseudarthroses Essentially all these factors exert their influence by impairment of the formation of the normal blood clot between the fractured fragments The effect of interposition of soft tissues between the bone ends is such as

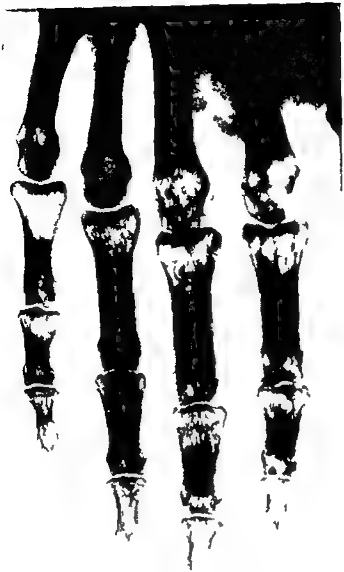


FIG 39 Sudeck's syndrome There is well marked lacunar type of osteoporosis in the phalanges and metacarpal heads of the index and middle fingers This type of bone atrophy is characteristically seen in conditions where there is vasodilatation and arteriovenous shunts

firmatory evidence of the existence of the Sudeck's syndrome it is not pathognomonic and other conditions such as tuberculosis or atrophy of disuse, may simulate it (Fig 41)

The generally accepted pathophysiology of the condition is that of arteriolar dilatation with increased peripheral blood flow This accounts for the roentgenographic appearance of the lacunar type of osteoporosis that may be due to the development of the same type of arteriovenous shunts as are present in Paget's disease of bone This might also account for the characteristic throbbing nature of the pain of which the patient usually complains

CHAPTER 5

Sudeck's Syndrome

In 1900 Sudeck first described a condition that has since appeared in the literature under a variety of names traumatic osteoporosis, chronic posttraumatic edema, posttraumatic peripheral trophoneurosis, reflex sympathetic dystrophy, and posttraumatic atrophy of bone Each of these designations emphasizes one or another aspect of the clinical picture that, in truth, combines all these different phases

The condition arises after relatively minor injuries such as sprains, sprain fractures and avulsions or fractures of the distal portions of an extremity It seldom arises in consequence of trauma resulting in fracture of the long bones or frank injury to the large neurovascular structures The severity of the reaction appears to bear no relation to the severity of the injury Relatively minor trauma may lead to a prolonged disability that has been called a minor causalgia " The mild cases usually subside spontaneously within several weeks but the more severe cases may require as much as a year to resolve and some cases may persist permanently with intractable pain swelling and stiffness of the limb

The syndrome is characterized by pain vasomotor disturbances particularly edema increased peripheral blood flow and later by a peculiar lacunar type of bone atrophy that may eventuate in a diffuse atrophy of the entire bone The first symptom is almost invariably that of pain Pain is usually continuous and of a *throbbing or burning nature In the beginning it is localized to the involved portion* of the extremity but may later spread centrally to involve the entire extremity the trunk or even the opposite unaffected limb The skin is at first characteristically red and warm owing to arteriolar vasodilatation with increased blood flow through the extremity As the condition becomes chronic however the skin assumes a cold cyanotic glossy appearance although blood flow determinations indicate a continuance of increased flow The periarticular edema which is primarily localized may later spread and lead to marked limitation of motion

Several weeks after the incidence of the injury roentgenograms of the involved region present signs of a lacunar spotty osteoporosis that has been considered characteristic of the condition (Figs 39 and 40) While the x ray affords con-

substance' that causes vasodilatation by stimulation of vasodilator efferent fibers in the dorsal root system Sympathectomy, by increasing the rate and total volume of blood flow, would thus act to dilute this substance and, hence, lead to amelioration of the pain The fourth theory assumes that the characteristic arteriolar vasodilatation is associated with concomitant constriction of the capillary bed Taken in conjunction with the fact that there is increased blood flow, this could be possible only in the event that arteriovenous shunts, such as might be indicated on the basis of the roentgen appearance of the bone, had developed Throbbing pain might then be explained by the obstruction offered by the constricted capillary bed, and relief of pain following sympathectomy, by overcoming of the obstruction

Irrespective of the details of the actual mechanism there is no doubt but that interruption of the sympathetic fibers is distinctly beneficial The crux of the clinical problem is the avoidance of the disability that development of the chronic phase of the syndrome entails In the earlier stages, treatment should be directed to the control of pain by careful and rigid immobilization If pain persists, it should be combatted by local and paravertebral ganglionic blocks Sympathectomy, however, is useless except in those cases in which temporary relief has been obtained by these methods

There appears to be a predisposition of certain patients to the development of Sudeck s syndrome, but there is no objective method of predetermining the likelihood of its occurrence The only safe method is that of prevention by careful attention to the immobilization of what might appear to be minor injuries

FIG 40 Sudeck s syndrome The characteristic lacunar type of bone atrophy is present in the lower end of the tibia the tarsal bones and the metatarsal bases

FIG 41 Tuberculosis of the wrist There is a lacunar type of bone atrophy which is somewhat suggestive of that seen in Sudeck s syndrome The differentiation must be made on other than roentgenographic evidence

A number of different theories have been evolved to explain the relief of pain following sympathectomy despite the fact that there is persistence or even increase in arteriolar dilatation and peripheral blood flow One of these is based upon the assumption that both the pain and the vasodilatation are mediated by sympathetic efferent vasodilator fibers This is however negated by the fact that sympathectomy relieves the pain without abolishing vasodilatation Another postulates that pain which is the cause of the vasodilatation is transmitted through sympathetic afferent fibers Were this the case sympathectomy would, to be sure, relieve the pain but should at the same time lead to subsidence of vasodilatation This is clearly not the case

A third theory is based upon the assumption of a locally acting diffusable pain

of the surgeon For this reason, it is often desirable to maintain position after an attempt at reduction by means of a light plaster mold, which may be either skin-tight or held to the skin by means of elastic or gauze bandages, pending roentgenographic visualization

Manipulation, however, is not always practical or applicable even when there is a distal fragment of sufficient size to control The swelling of soft tissues by hemorrhage or edema, the existence of cutaneous defects or blebs, marked overriding of the bony fragments, or the presence of a heavy layer of muscles frequently vitiates the most skilled efforts at manual replacement of the fragments In these instances, either skeletal or skin traction must be applied

Traction

Theoretically, traction for the purpose of reduction should be of an order of magnitude commensurate with, but not appreciably greater than, the strength of the muscles that cross the fracture line Practically, however, it will be found that traction required for adequate reduction must be somewhat greater than the strength of the muscles in the vicinity of the fracture site, while traction for maintenance of position following reduction should be less than the strength of the surrounding muscles The most convenient method for determining the precise amount of weight to be added to the traction apparatus is to add weights successively until the fracture can either be felt to have been actually reduced or until the roentgenogram shows it to have been reduced

In this context, it is absolutely necessary that frequent roentgenograms be made of the fracture site, including films of both ends of the bone, to rule out the development of postreduction axial malalignments

Traction either for reduction or for maintenance, may be applied rapidly by means of screw action as when the fracture table is used in conjunction with manual replacement of the fractured fragment, or more slowly by means of skin or skeletal traction

Skin Traction

A most convenient and effective means of obtaining skin traction can be accomplished by facing the adhesive or moleskin traction strips with a layer of sponge rubber approximately one-half inch thick The sponge rubber side of the traction strip is applied directly to the washed skin and held against the part by elastic or gauze bandages (Figs 42 and 43) The numerous air pockets of the sponge rubber act as effective vacuum cups to maintain skin adhesion and afford satisfactory mechanical traction while obviating the drawbacks inherent in other methods of skin traction

Skin traction cannot however be used satisfactorily where the weight necessary to counteract the muscular pull exceeds twenty-five pounds Furthermore skin traction has the disadvantage that it cannot be used where the skin is contused

CHAPTER 6

Reduction of Fractures

Reduction of a fracture may be accomplished either by closed, nonoperative, or by open, surgical methods. Closed reduction, particularly in uncomplicated, simple (closed) fractures, may be obtained either by manipulation of the fragments, by traction on the distal fragment, or by a combination of these methods.

CLOSED REDUCTION

Manipulation

Manipulation has the advantage of permitting early and accurate adjustment of the axial relationship of the distal to the proximal fragment without the potential danger of contaminating the fracture wound. Manipulative reduction involves "laying on of the hands" in a literal sense. The fracture ends must be palpated and grasped between the fingers of the surgeon. The proximal fragment should be held fixed, preferably by the nondominant hand; the distal fragment should, if loose, be grasped by the dominant hand and be pulled, pushed, or levered into a position where the fracture ends are in contact and the normal axial alignment is re-established. Where the distal fragment is impacted, the impaction must be broken loose. This may be accomplished by manual traction in the direction of the anatomical axis of the distal fragment or by alternatingly bending the fragment in opposite directions.

Properly executed under either local or general anesthesia, manipulative methods effect correction of the axial malalignment in many fractures. It is, however, possible only when the fragments are sufficiently large to permit of accurate control of the alignment by palpation, and involves careful attention to the anatomical configuration of both fragments of the bone.

Roentgenographic and fluoroscopic control of the manipulative procedure is an absolute *sine qua non*, despite the fact that these methods, and fluoroscopy in particular, carry with them the distinct disadvantage of radiation effects on the hands

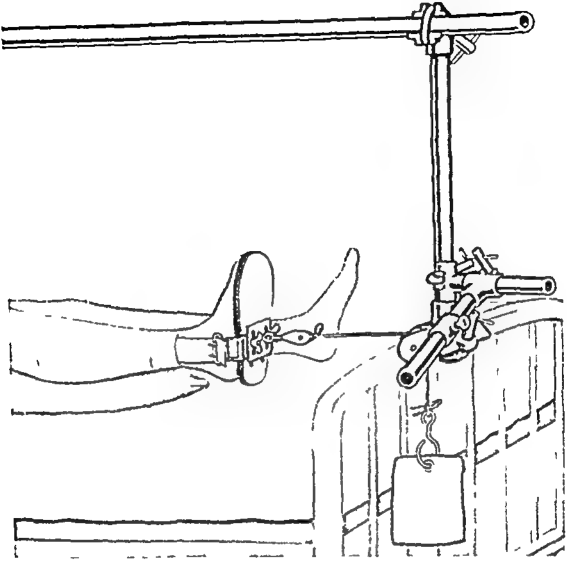


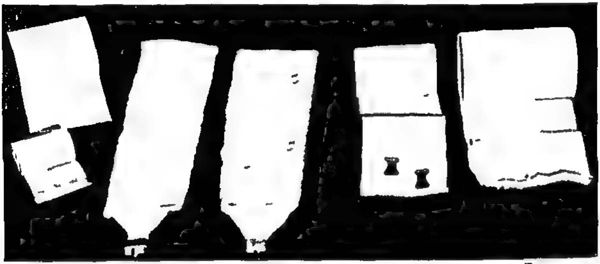
FIG 43 Application of skin traction Moleskin traction strips with a buckle are applied to either side of the leg and are held in position by a circular bandage The buckles are attached to the footplate from which the traction weights are suspended A pillow is placed beneath the knee and leg to maintain extension of the limb and to prevent pressure on the heel The foot of the bed should be elevated to augment the countertraction afforded by the body weight

Skeletal Traction

Skeletal traction, in which a nail pin, or wire transfixes one or both of the fractured fragments is without doubt the more efficient means of obtaining axial alignment but it carries with it the unquestioned potential danger of infection and necrosis at the sites of insertion of the transfixion device In contradistinction to skin traction where the force is only indirectly applied to the affected bone, skeletal traction permits direct application of the traction weights The primary purpose of skeletal traction is served by transfixion of the distal fragment of the fractured bone by means of a Kirschner wire Steinman pin or stirrup to which the traction weights are applied (Figs 44 and 45) Where the condition of the skin directly over

or abraded or where there is bullous, cutaneous edema It should never be used where encircling bandages required to fix the traction strips to cutaneous areas may further jeopardize an already embarrassed circulation

In some clinics, custom has dictated that careful skin preparation should precede the application of skin traction and, accordingly, considerable effort has often been directed to shaving of the skin and the application of either tincture of benzoin or various adhesive substances It will be found that careful washing of the skin surface, preferably with a surface acting detergent, followed by careful drying of the area provides a satisfactory method of skin preparation for the application of



A B C D E

FIG 42 Skin traction materials *B* is the outer surface of the moleskin traction strip fitted with a buckle for the application of the traction weights *C* is the inner surface of the traction strip which is faced with sponge rubber for application directly against the skin The traction strips are held against the skin by *A* gauze bandages *D* elastic bandage or *E* neuroroll gauze

skin traction It obviates many of the hazards that shaving and covering the skin surface involve Superficial infection beneath the traction strips occurs more frequently after the skin has been abraded by careful shaving followed by the application of a nonporous adhesive material than under those conditions in which the unabraded uncontused skin is covered by a material as relatively porous as is moleskin or adhesive tape Similarly perspiration which tends to decrease the adhesion of traction strips to the skin by causing collections of pools of sweat between the skin surface and the traction strip is less likely under moleskin or adhesive tape than under the chemical films of the various commercially available adhesive and skin protecting substances If it is nevertheless desired to use these materials in the application of skin traction it is important to limit the area of their application to the skin areas to which the traction strips are to be applied and never to cover the entire circumference of the part

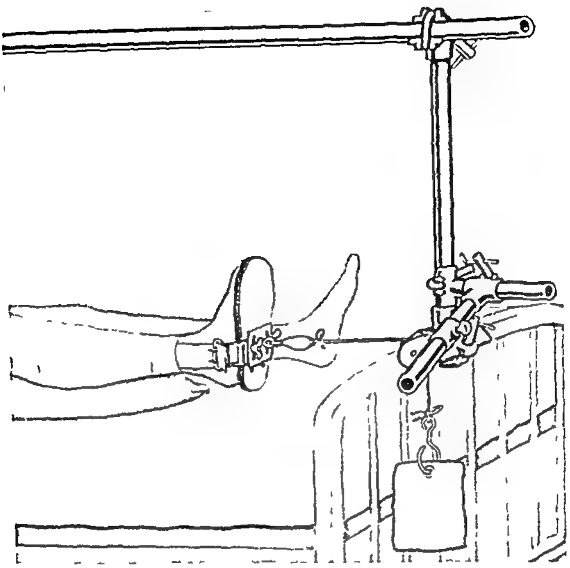


FIG 43 Application of skin traction Moleskin traction strips with a buckle are applied to either side of the leg and are held in position by a circular bandage The buckles are attached to the footplate from which the traction weights are suspended A pillow is placed beneath the knee and leg to maintain extension of the limb and to prevent pressure on the heel The foot of the bed should be elevated to augment the countertraction afforded by the body weight

SKELETAL TRACTION

Skeletal traction, in which a nail pin or wire transfixes one or both of the fractured fragments is without doubt the more efficient means of obtaining axial alignment but it carries with it the unquestioned potential danger of infection and necrosis at the sites of insertion of the transfixion device In contradistinction to skin traction where the force is only indirectly applied to the affected bone, skeletal traction *permits direct application of the traction weights The primary purpose of* skeletal traction is served by transfixion of the distal fragment of the fractured bone by means of a Kirschner wire, Steinman pin or stirrup to which the traction weights are applied (Figs 44 and 45) Where the condition of the skin directly over

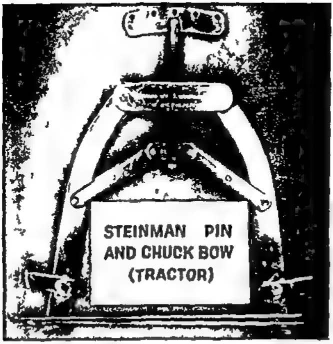


FIG 44 Steinman nails and traction bow After passage through the bone the Steinman nail is locked in the traction bow Weights can be attached through hooks passed through the perforations in the tension screw

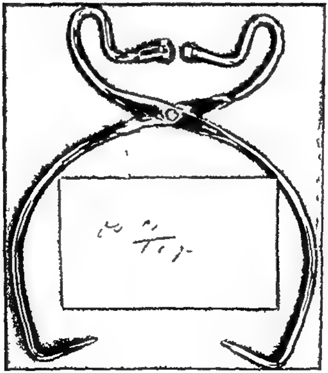


FIG 45 Os calcis tongs The prongs are inserted directly into the bone Application of weights to the oposite end of the tongs serves to firmly fix the prong in the cortex

the fracture site is such as to preclude insertion into the distal fragment, skeletal traction may be effected across the neighboring joint by insertion of the transfixion wire or pin into the adjacent portion of the distally located bone (see below)

The insertion of wires or other devices for skeletal traction should be undertaken only after skin preparation commensurate with that of any other surgical procedure For cleansing, a surface-acting detergent alone is sufficient, but in some clinics alternating alcohol and benzalkonium sponges or iodine and alcohol sponges are preferred The details are not very important so long as it is remembered that from a microbiological point of view there is only a difference in the size of the operative wound between preparation of the skin for skeletal traction fixation and preparation of the skin for open, operative reduction of the fracture

Transfixion pins or wires should be selected for strength, elasticity, and outside diameter with reference to the diameter of the bone in which they are to be used To avoid the danger of pressure necrosis at the site of entry and emergence, small longitudinal skin incisions may be made at these points This is, however, usually not necessary Pins may be inserted directly through the skin at the selected site without preliminary incision if the skin is stretched slightly in a direction opposed to the direction of the ultimate traction force

The pin may be inserted by either a hand or electric drill When an electric drill is used the rotatory speed of the drill chuck should be carefully controlled and reduced so as to avoid binding and burning of the skin as well as burning of the bone through which the drill point passes Burning of the bone is the most common cause for necrosis about the pin in its bony canal and predisposes to insecure fixation of the fragment and possible secondary infection In like manner burning and necrosis of the skin may lead to infection about the pin and thus to secondary infection of the bone

It is essential that the direction of the pin be carefully checked and controlled before and after penetration of the opposite cortex of the bone to be transfixed To prevent angulation the transfixion pin should be inserted at right angles to the long axis of the distal fragment and, to prevent rotation, exactly in the frontal plane of the bone Unless absolutely right-angled transfixion can be assured, the value of the skeletal traction obtained will be largely mitigated and will require constant readjustment The wire or pin should be drilled and not hammered through the bone, to prevent splitting of the opposite cortex The traction stirrup to which the weights are applied should be placed as close to the bone as the thickness of the surrounding musculature and the local condition of the skin will permit Where plaster of Paris is used to encase the distal portion of the extremity it is desirable to include the pin ends in the plaster of Paris cast so as to prevent excessive lateral motion

When pin fixation is used in the upper extremity it may be inserted through the lower condylar region of the humerus, through the base of the olecranon process through the lower end of the radius or through the metacarpals (Fig 46)

For fractures of the lower end of the femur the pin may be inserted above the condylar flare or if this is impossible through the upper end of the tibia at the level of the tibial tubercle This latter point of insertion carries with it the danger of relaxation of the collateral ligaments of the knee joint and should not be used over

prolonged periods of time For fractures of the leg, the transfixion pin may be inserted just above the ankle joint or through the os calcis (Fig 47) Prolonged use of skeletal traction is possible only where there is firm cortical bone to support the weight Spongy bone is useful only for shorter periods of time since the pin cuts through the relatively lower resistant bone

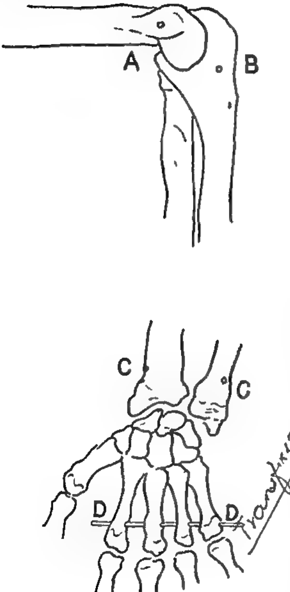


Fig 46 Major sites for the insertion of skeletal traction wires in the upper extremity (*A*) Through the lower end of the humerus just above the medial condyle and midway between its anterior and posterior surfaces (*B*) Through the olecranon one inch below the tip of the olecranon process and about one half inch beneath the skin surface (*C*) Through the lower end of the forearm between one inch and one and a half inches above the tip of the radial styloid midway between its anterior and posterior borders and impaling the ulna if possible (*D*) Through the metacarpal heads about one half inch above the mid portion of the head of the metacarpal to the index finger The second and third or the second through the fourth metacarpal heads should be transfixed leaving the thumb free

Protection of the skin about the points of entry and exit of the transfixing wires varies in different clinics Simply covering the skin immediately about the drill holes with collodion covering this with a small pledget of gauze soaked with collodion and then placing a small square of sponge rubber over the gauze has proved a reasonably satisfactory method Corks or rubber stoppers placed over the ends of the transfixing wires cut beyond the traction bow will protect the patient as well as the nursing and medical personnel involved in the patient's later care

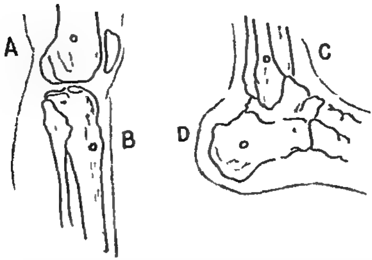


Fig 47 Major sites for the insertion of skeletal traction wires in the lower extremity (*A*) Through the lower end of the femur just above the prominence of the lateral condyle about one and a half inches above the articular surface and midway between the anterior and posterior surfaces of the bone (*B*) Through the upper end of the tibia about a half inch below the prominence of the tibial tubercle and three quarters of an inch behind the anterior surface of the tibial crest (*C*) Through the lower end of the tibia just above the prominence of the medial malleolus and midway between its anterior and posterior borders (*D*) Through the os calcis about three quarters of an inch below the tip of the lateral malleolus and about three quarters of an inch behind the axis of the fibula

Prophylactic antiseptic and antibiotic solutions have no place in local treatment about the transfixing pins If serious infection ultimately ensues, the treatment of choice is removal of the pins or wires Osteomyelitis, if it develops, is treated as is osteomyelitis due to other causes

Skeletal traction may be used in infected fractures provided the traction is inserted sufficiently distant from the site of the infection It is preferable in these fractures however, to insert the transfixing pins in an adjacent bone

Buck s Extension

Buck s extension is the basic method of skin traction (Fig 48) It is, characteristically traction exerted along the longitudinal axis of the involved extremity by means of laterally and medially fixed traction strips The traction strips may be either of adhesive tape or moleskin adhesive (for adults about three inches in width) that are held to the skin by means of a circularly applied elastic bandage Better fixation of the adhesive strips can be obtained by splitting the upper end of the traction strips longitudinally and spreading them slightly so as to cover a wider area of the skin surface

prolonged periods of time For fractures of the leg, the transfixion pin may be inserted just above the ankle joint or through the os calcis (Fig 47) Prolonged use of skeletal traction is possible only where there is firm cortical bone to support the weight Spongy bone is useful only for shorter periods of time since the pin cuts through the relatively lower resistant bone

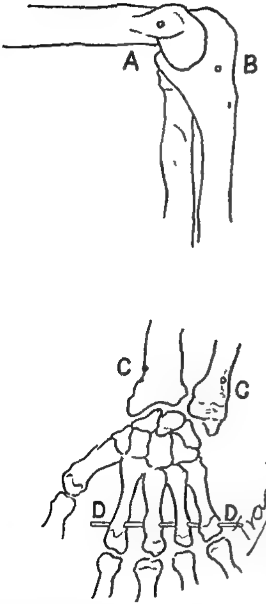


FIG 46 Major sites for the insertion of skeletal traction wires in the upper extremity (*A*) Through the lower end of the humerus just above the medial condyle and midway between its anterior and posterior surfaces (*B*) Through the olecranon one inch below the tip of the olecranon process and about one half inch beneath the skin surface (*C*) Through the lower end of the forearm between one inch and one and a half inches above the tip of the radial styloid midway between its anterior and posterior borders and impaling the ulna if possible (*D*) Through the metacarpal heads about one half inch above the mid portion of the head of the metacarpal to the index finger The second and third or the second through the fourth metacarpal heads should be transfixed leaving the thumb free

Protection of the skin about the points of entry and exit of the transfixing wires varies in different clinics Simply covering the skin immediately about the drill holes with collodion covering this with a small pledget of gauze soaked with collodion, and then placing a small square of sponge rubber over the gauze has proved a reasonably satisfactory method Corks or rubber stoppers placed over the ends of the transfixing wires cut beyond the traction bow will protect the patient as well as the nursing and medical personnel involved in the patient s later care

be somewhat mitigated by elevating the foot of the bed on shock blocks and should be done in all cases in which Buck's extension is used In patients with congestive heart failure, care must be taken to avoid elevating the extremity above the level of the right atrium lest the congestive failure be exacerbated To prevent foot drop, a footboard should be incorporated

Modified Buck's Extension

Additional countertraction can be achieved without increasing the elevation of the bed by applying a Thomas or a Jones splint to the extremity and exerting traction against the splint (Fig 49)

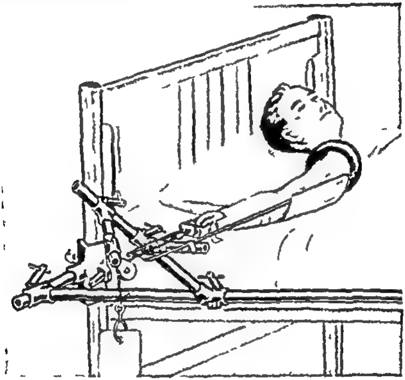


Fig 49 Modified Buck s extension A humerus splint has been fixed to the extension rod and applied snugly against the axilla to act as countertraction Traction on the arm is obtained by a Buck's extension over a pulley fixed to the extension rod beyond the splint (Courtesy of Gilbert Hyde Chick Co)

While angulational and lineal malalignments are usually amenable to the longitudinal force exerted through Buck s extension apparatus, it is frequently necessary to counteract a tendency toward torsion or transposition This can be accomplished by properly placed sandbags, Cole pressure pads attached to the splint, or by movable derotating forces acting over pulleys but at right angles to the primary traction Where it is desirable to preserve mobility of an intervening joint, as the elbow joint in fractures of the humerus or the knee joint in fractures of the femur, methods of balanced suspension must be used

Since traction causes the skin overlying a fracture to be displaced somewhat distally, the upper limit of the traction strips should be placed just at the level of the fracture Distally, the strips should extend beyond the limit of the extremity so as to permit of their attachment to a spreader by means of which weight traction may be exerted The spreader should be sufficiently wide to prevent pressure against the bony prominences of the distal joint of the fractured extremity Occasionally it may be desirable to further protect these regions by placing either a coil of rolled stockinette or loosely applied felt pads over the bony projections The same objectives

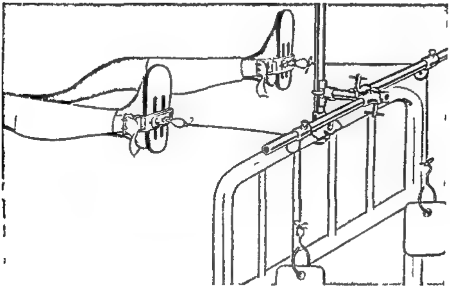


FIG 48 Buck s extension Traction strips are secured to each leg from just above the ankle joint A combination footplate and spreader to which the traction weight is attached has been buckled to each traction strip to prevent pressure on the ankle joint and dropped foot Pillows should be placed under the legs and knees and the foot of the bed should be elevated (Courtesy of Gilbert Hyde Chick Co)

may be obtained by wrapping the joint with ordinary gauze and then incorporating the ends of the traction strips in the bandage This protects the bony prominence of the joint, permits motion of the joint and, at the same time, fixes the most distal end of the traction strips so as to minimize slipping

Although Buck s extension apparatus can be assembled quickly it has been found more convenient to have its component parts prepared in advance Moleskin strips of sufficient length are fitted with small buckles Metal spreaders with leather straps or wooden spreaders with a central hole to accommodate the traction rope are fitted with leather straps that can be attached to the buckles on the moleskin traction strips

In the use of the classic Buck s extension apparatus, the weight of the body acts as countertraction There is, consequently, a tendency of the body to be pulled down toward the foot of the bed with loss of the effective traction force This can

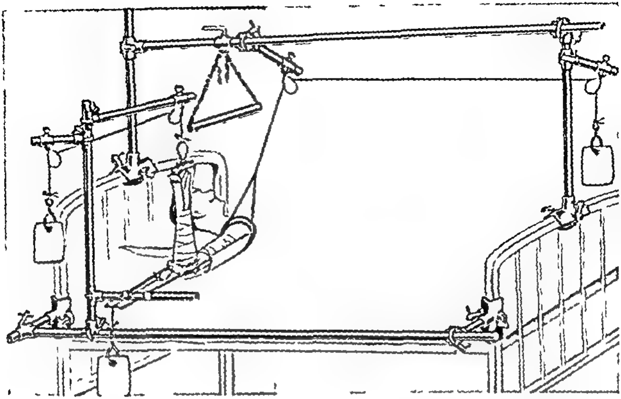


FIG 51 Balanced suspension for fracture of the humerus A modified Buck's extension has been applied to the arm for traction purposes The forearm is flexed to a right angle and is suspended from an overhead frame by simple Buck's extension, which permits motion of the elbow while maintaining traction on the arm A hand grip should be incorporated to permit motion of the fingers

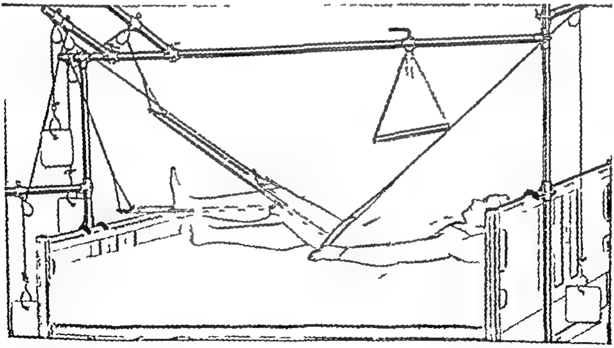


FIG 52 Balanced suspension for fracture of the femur Traction is exerted through a pin transfixing the lower end of the femur The limb rests on a Thomas splint with a Pearson attachment to permit motion at the knee joint The foot of the bed should be elevated to prevent downward sliding of the patient and afford additional countertraction An overhead bar should be attached to the frame to facilitate nursing care (Courtesy of Gilbert Hyde Chick Co)

Balanced Suspension Traction

Balanced suspension involves the setting up of an overhead frame to which pulleys over which the traction ropes may be passed, are suspended It is used mainly in the treatment of fractures of the lower extremity (Fig 50) or of the humerus (Fig 51) Many different types of overhead frames have been devised and are available commercially The prototype, the Balkan frame, consists of four uprights to which crosspieces for fixing the pulleys are attached

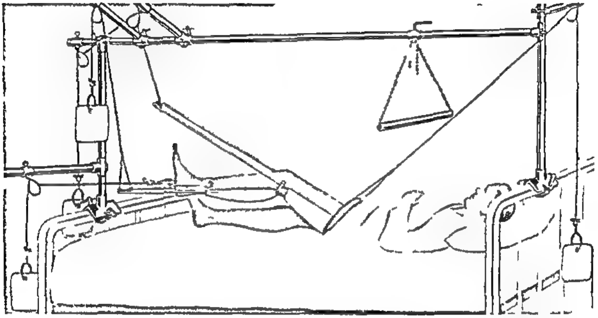


Fig 50 Balanced suspension for fracture of the femur The thigh is supported on a Thomas splint which is suspended from the overhead frame The leg is supported on a Pearson attachment to the Thomas splint to allow motion at the knee joint Traction is maintained on the femur by skeletal traction applied through a transtibial pin The foot of the bed should be elevated (See also Figs 368 369 and 370) (Courtesy of Gilbert Hyde Chick Co)

The purpose of balanced suspension in the lower extremity is to permit longitudinal traction on a femur that is held in slight flexion (Fig 52) This counteracts the tendency toward angulation that ordinary Buck's extension might effect In addition it permits mobility of the patient in bed without loss of the traction force and thus materially increases the ease of nursing care A Thomas or a Hodgen splint is applied and is balanced in a position of flexion by ropes attached to both ends of the splint A single balancing weight sufficiently great to maintain the desired degree of flexion may be suspended from the frame over the involved extremity by means of a single rope passing over two pulleys and attached to either end of the splint This is sometimes disturbing to the patient and in this event, each end of the splint may be suspended by separate weights passing over the pulleys attached to the end of the frame so that the weights are suspended over each end of the bed Traction on the fractured limb is then exerted by means of Buck s extension strips

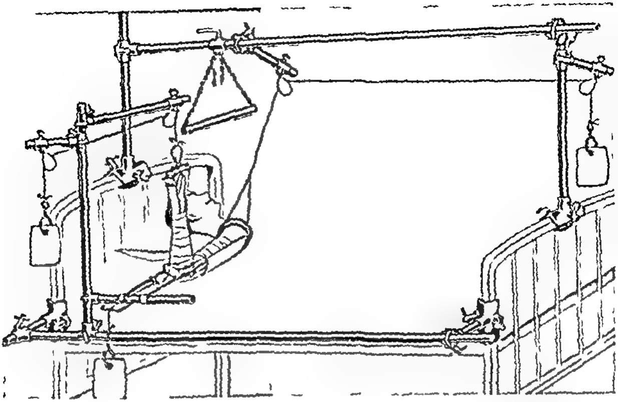


Fig 51 Balanced suspension *for fracture of the humerus* A *modified* Buck s extension has been applied to the arm for traction purposes The forearm is flexed to a right angle and is suspended from an overhead frame by simple Buck s extension which permits motion of the elbow while maintaining traction on the arm A hand grip should be incorporated to permit motion of the fingers

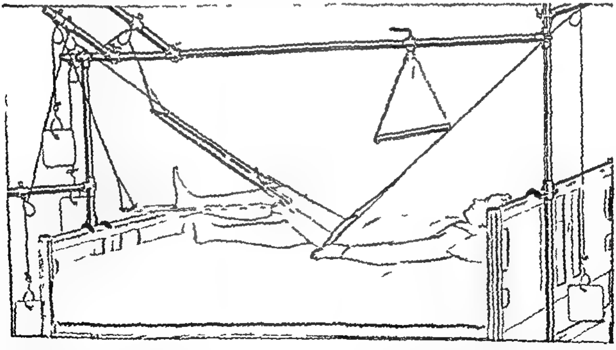


Fig 52 Balanced suspension for fracture of the femur Traction *is exerted through* a pin transfixing the lower end of the femur The limb rests on a Thomas splint with a Pearson attachment to permit motion at the knee joint The foot of the bed should be elevated to prevent downward sliding of the patient and afford additional counter-traction An overhead bar should be attached to the frame to facilitate nursing care (Courtesy of Gilbert Hyde Chick Co)

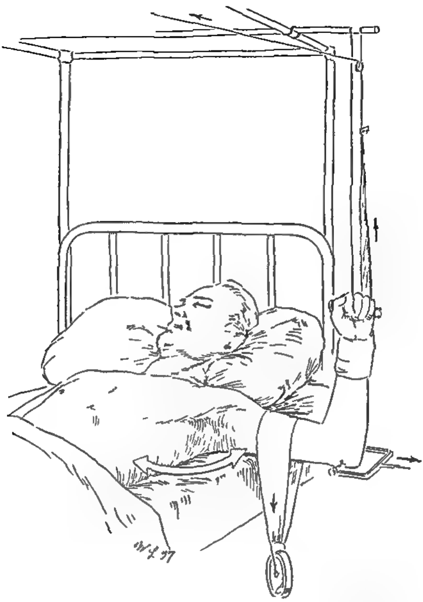


FIG 53 Skeletal traction for fracture of the humerus A Kirschner wire has been passed through the olecranon process and traction weights are suspended over a pulley The elbow is supported in a right angle position by a wrist cuff A hand grip to permit motion of the fingers has been incorporated

that are attached in the usual manner The strips may be attached either to the end of the splint to give fixed traction or over an additional pulley with the weight hanging over the foot of the bed

Where skin traction cannot be used, skeletal traction using a Steinman pin or occasionally a Kirschner wire may be employed in the same apparatus and with the same objectives (Fig 53)

When it is desired to maintain mobility of the knee joint, a Pearson attachment is affixed to the Thomas splint permitting flexion of the knee In this event the attachment must be separately supported by a rope passing over a pulley, thus per-

mitting the patient passively to flex and extend the knee by pulling on the rope A footboard must be fixed to the Pearson attachment to prevent foot drop A hand grip should be supplied at the upper end of the frame to permit the patient to move about in bed in all instances of balanced suspension for the lower extremity

In the upper extremity, the Balkan frame is not absolutely necessary Skin traction may be applied to the humerus in the usual manner over a pulley attached to the side of the bed or over a modified Thomas (Murray-Jones) splint, as in the lower extremity To preserve motion of the elbow, a second set of Buck's extension strips is applied (see Fig 51) The elbow is flexed to ninety degrees and the traction rope is suspended over a pulley with sufficient weight (usually two to five pounds) to support the forearm This permits motion of the elbow without disturbing the traction exerted on the fractured humerus by the primary set of Buck's extension strips It is extremely important to incorporate a hand grip in the second set of extension strips so as to permit motion of the fingers The finger grip can be readily made by suspending several well padded tongue depressors from the proximal side of the rope attached to the spreader The bed should be elevated on shock blocks on the side of the bed over which the traction is being exerted in a manner comparable to that used for elevating the foot of the bed in the lower extremity The cardinal principle in each is the use of the patient's body as a countertraction force

Bryant's Traction

Special attention must be directed to that form of extension traction applied with the thigh in flexion on the trunk which has its specific field of usefulness in fractures of the femur in children Because of the attitude of universal flexion in which the fetus develops extension of the thigh is limited by the action of the iliopsoas muscle and the Y-shaped ligament of Bigelow In the postnatal period the thigh begins gradually to extend until it makes with a line joining the anterior superior iliac spine and the ischial tuberosity (Nelaton s line) a downward and backward opening angle of fifty degrees This *pelvifemoral angle* is fairly constant in all ages and in both sexes and determines the limit of extension of the thigh on the pelvis Further extension of the thigh takes place as a result of flexion of the pelvis and thus accounts for the development of the normal lumbar lordosis

In the young child before adaptive flexion of the pelvis has occurred the thigh is in a position of flexion with respect to the pelvis and any effort at the application of extension traction serves to create forward angulation at the site of fracture in the femoral shaft To overcome this Bryant applied traction on the distal fragment in the axial direction of the proximal fragment Although Bryant originally suspended only the involved femur, better control of the patient and the fracture can be obtained by suspending both the injured and the uninjured extremities in the overhead traction apparatus

Ordinary Buck s extension strips are applied to both legs and are held against the skin in the usual manner The traction rope for each leg is passed over a single pulley and weights sufficient to just raise the child s buttocks from the mattress are

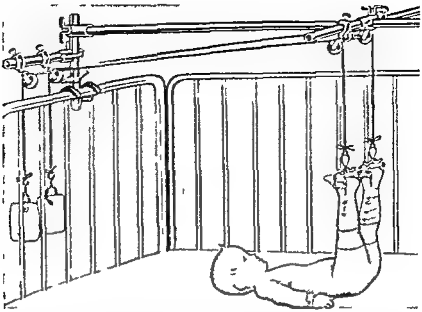


FIG 54 Bryant s traction Buck s extension traction strips are applied to each leg and each is separately suspended by weights from the overhead frame The combined weights are just sufficient to raise the child s buttocks from the bed so that the weight of the trunk acts as countertraction A restraining sheet about the chest may be necessary to control the child in the traction apparatus Even when only one extremity is affected both legs should be incorporated into the traction apparatus to obtain maximal traction (Courtesy of Gilbert Hyde Chick Co)

suspended over the end of the bed In this manner the weight of the child s body provides countertraction (Fig 54)

MODIFIED BRYANT S TRACTION

Classic Bryant s traction apparatus requires constant attention and therefore prolonged hospitalization Where hospitalization is impossible, a portable modification of Bryant s traction has been devised A plaster body jacket is applied from the nipple line to just above the inguinal fold anteriorly and from below the angle of the scapula to the iliac crests posteriorly As in the preparation of all body casts several folded towels are placed anteriorly beneath the padding during the application of the cast Removal of the towels after the cast has been completed avoids the necessity of subsequently cutting a window over the abdomen and weakening of the cast A long steel rod bent at ninety degrees is incorporated in the plaster jacket and at the distal end of the rod which projects beyond the sole of the child s foot a loop is made for the attachment of a traction rope When the cast has set and dried the Buck s extension traction strips are fastened to the upper end of the projecting steel rod which acts in lieu of an overhead frame The traction rope may be fixed directly to the rod or by the incorporation of elastic bands or rubber tubing between the rope and the rod, elastic traction may be exerted (Fig 55) As in

ordinary Buck's extension, the traction must be of sufficient magnitude to secure end-to-end apposition of the fragments. Although this is the ideal method of treatment, end-to-end apposition is not essential in children and, provided lineal alignment is attained, even a slight amount of overriding of the fragments is tolerable.

This affords a simple method of extension traction that is self-contained so that the child can be moved and cleansed in the flexed position. Moreover, it permits the assumption of the seated position so that the leg itself may be brought below the level of the heart without in any manner disturbing the continuance of traction.

This is especially important in the light of a number of reported instances in which circulatory disturbances, leading even to gangrene, have been reported following the use of overhead traction. Experimental evidence seems to indicate that

FIG 55. Portable Bryant's traction. A plaster of Paris body cast has been applied and a steel rod bent at ninety degrees has been incorporated in the jacket. Buck's extension strips are applied to the leg and traction is made in the flexed position over the end of the steel rod. (Reproduced from Milch, H.: *Portable extremity traction for children. J. Bone & Joint Surg.* 19: 1134, 1937.)

the primary cause of the circulatory impairment has been the reduction in peripheral blood pressure owing to elevation of the limb beyond the point at which the hydrostatic force of the heart can supply adequate blood to the distal structures. Other factors, such as tight bandaging and hyperextension of the knee, unquestionably play a secondary role. The method of self-contained Bryant's traction noted above seems to offer a simple solution to the dilemma that classic Bryant's traction imposes.

Russell's Traction

Russell's traction is almost specifically indicated in the treatment of fractures of the femoral shaft in the adult. By allowing the application of longitudinal traction with the hip in flexion, it minimizes the tendency toward forward angulation exerted by the hip flexors when traction is applied in complete extension. Because the traction is applied only to the leg, it is especially valuable in lesions of the femur where the condition of the skin of the thigh prevents the direct attachment of traction

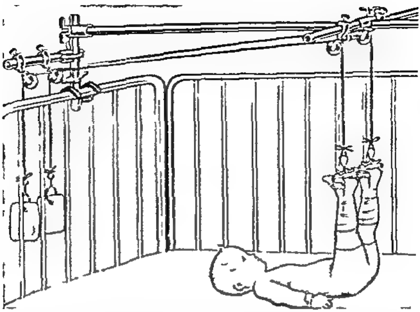


FIG 54 Bryant s traction Buck s extension traction strips are applied to each leg and each is separately suspended by weights from the overhead frame The combined weights are just sufficient to raise the child s buttocks from the bed so that the weight of the trunk acts as countertraction A restraining sheet about the chest may be necessary to control the child in the traction apparatus Even when only one extremity is affected both legs should be incorporated into the traction apparatus to obtain maximal traction (Courtesy of Gilbert Hyde Chick Co)

suspended over the end of the bed In this manner, the weight of the child s body provides countertraction (Fig 54)

MODIFIED BRYANT S TRACTION

Classic Bryant s traction apparatus requires constant attention and therefore prolonged hospitalization Where hospitalization is impossible a portable modification of Bryant s traction has been devised A plaster body jacket is applied from the nipple line to just above the inguinal fold anteriorly and from below the angle of the scapula to the iliac crests posteriorly As in the preparation of all body casts several folded towels are placed anteriorly beneath the padding during the application of the cast Removal of the towels after the cast has been completed avoids the necessity of subsequently cutting a window over the abdomen and weakening of the cast A long steel rod bent at ninety degrees is incorporated in the plaster jacket and at the distal end of the rod which projects beyond the sole of the child s foot, a loop is made for the attachment of a traction rope When the cast has set and dried the Buck s extension traction strips are fastened to the upper end of the projecting steel rod, which acts in lieu of an overhead frame The traction rope may be fixed directly to the rod or by the incorporation of elastic bands or rubber tubing between the rope and the rod elastic traction may be exerted (Fig 55) As in

being exerted along the tibia The actual force of reduction is the resultant of the parallelogram of forces thus constituted and will be in the longitudinal axis of the flexed fractured femur

Efficient use of Russell's traction depends upon meticulous attention to the mechanical setup The overhead pulley must be at the level of the tibial tubercle The other pullies over which the traction force is to be effected must all lie in the same vertical plane as the leg, and the sling supporting the lower end of the femur must be moved distally or proximally so that the distal fragment lies in the normal axis of the fractured femur Thus, all tendency toward angulation at the site of fracture is eliminated Where the force necessary to restore length and prevent angulation at the site of fracture exceeds twenty-five pounds, skeletal traction is unavoidable Balanced suspension traction with a Steinmann pin inserted at the level of the tibial tubercle must be employed

Dunlop s Traction

Dunlop s traction is specifically applicable to the treatment of supracondylar fractures of the humerus in children It accomplishes reduction of the small distal fragment and minimizes the additional risk of Volkmann's ischemia that treatment in the position of acute flexion imposes Its main drawback is that it necessitates hospitalization for a period of three weeks until callus has formed Thereafter, the

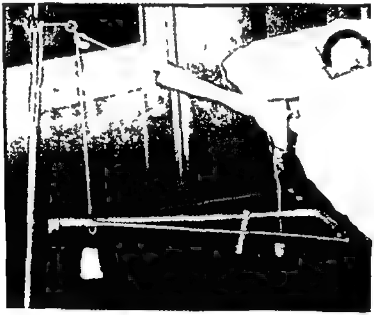


Fig 57 Dunlop s traction Buck s extension strips are attached to the forearm, and a six pound weight is suspended over a pulley so elevated as to flex the elbow to about thirty five degrees A counterweighted sling with three pounds of weight is placed over the distal end of the humerus above the fracture site to prevent elevation of the entire arm (Reproduced from Dunlop J Transcondylar fractures of the humerus *J Bone & Joint Surg* *21* 159 1939)

strips As a result of the mechanical advantage offered by the double pulley on the footpiece, the traction force on the skin is exactly double that of the attached weights

Russell s traction differs from the usual type of longitudinal traction in that its force is exerted not in the direction of the primary pull, but rather along the resultant of the forces exerted by the upward pull of the femoral sling and the longitudinal pull of Buck's extension In Russell s traction Buck's extension strips are ap

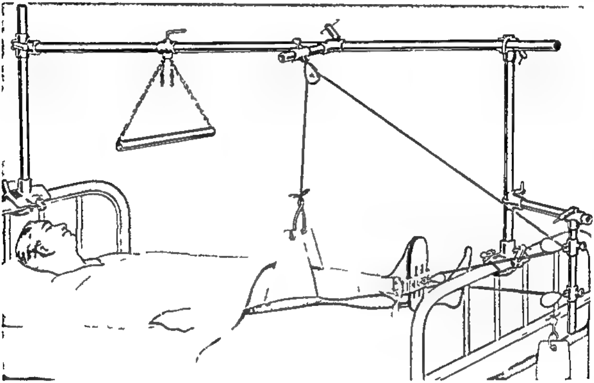


FIG 56 Russell s traction The overhead pulley is placed directly above the tibial tubercle The sling beneath the lower end of the femur is attached to a rope that passes through the overhead pulley and then over a set of double pulleys at the foot of the bed to mediate traction The traction force is consequently exactly twice that of the attached weights A pillow should be placed beneath the knee and the foot of the bed should be elevated (Courtesy of Gilbert Hyde Chick Co)

plied to the leg below the level of the knee joint and are attached to a spreader on the distal side of which a pulley is fixed A sling is then applied under the lower end of the femur to support the knee joint From this sling, the traction rope passes overhead across a pulley fixed directly above the level of the tibial tubercle The traction rope then passes downward to another pulley fixed to a crossbar at the foot of the bed From this the traction rope passes proximally to the pulley fixed to the Buck s extension spreader and then distally to another pulley from which the traction weight is suspended (Fig 56)

The resulting action of this pulley system is that an upward force is exerted by the sling against the lower end of the femur to bring the distal fragment in alignment with the flexed upper femur while at the same time a longitudinal force is

being exerted along the tibia The actual force of reduction is the resultant of the parallelogram of forces thus constituted and will be in the longitudinal axis of the flexed fractured femur

Efficient use of Russell's traction depends upon meticulous attention to the mechanical setup The overhead pulley must be at the level of the tibial tubercle The other pullies over which the traction force is to be effected must all lie in the same vertical plane as the leg and the sling supporting the lower end of the femur must be moved distally or proximally so that the distal fragment lies in the normal axis of the fractured femur Thus, all tendency toward angulation at the site of fracture is eliminated Where the force necessary to restore length and prevent angulation at the site of fracture exceeds twenty five pounds, skeletal traction is unavoidable Balanced suspension traction with a Steinmann pin inserted at the level of the tibial tubercle must be employed

Dunlop's Traction

Dunlop s traction is specifically applicable to the treatment of supracondylar fractures of the humerus in children It accomplishes reduction of the small distal fragment and minimizes the additional risk of Volkmann's ischemia that treatment in the position of acute flexion imposes Its main drawback is that it necessitates hospitalization for a period of three weeks until callus has formed Thereafter, the

Fig 57 Dunlop s traction Buck s extension strips are attached to the forearm and a six pound weight is suspended over a pulley so elevated as to flex the elbow to about thirty five degrees A counterweighted sling with three pounds of weight is placed over the distal end of the humerus above the fracture site to prevent elevation of the entire arm (Reproduced from Dunlop J Transcondylar fractures of the humerus *J Bone & Joint Surg* *21* 159 1939)

arm is supported in a sling and motion is started Buck s extension strips are attached to the forearm and a six-pound weight is suspended over a pulley so elevated that the forearm is flexed to about thirty-five degrees from the fully extended position of the arm To prevent upward displacement of the entire arm, a counterweight of about three pounds is suspended from a sling around the upper fragment of the humerus There is little danger of relaxation of the ligaments about the elbow because the actual reduction is mediated through the action of the olecranon against the lower fragment of the humerus (Fig 57)

Well-leg Countertraction Method

Anderson's well leg countertraction method has especial application in fractures involving the lower extremity and may be used in certain fractures of the pelvis not otherwise amenable to closed treatment The method involves the use of a special traction device (Fig 58) A long leg plaster of Paris cylinder is applied to the opposite unaffected leg The splint against which traction is exerted by the

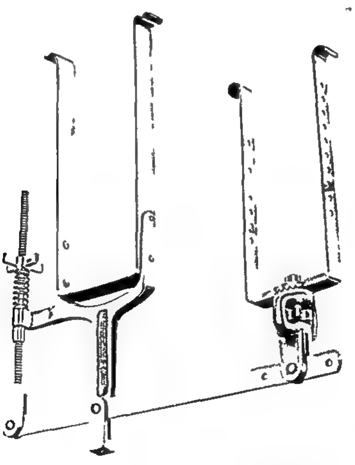


Fig 58 Well leg countertraction apparatus The shorter stirrup is for attachment to the Steinman pin that is inserted into the affected leg The longer stirrup is used to effect countertraction on the well leg (Courtesy of Dr Roger Anderson)

stirrup is incorporated into the well leg cast A Steinmann pin is then inserted into the tibia at a point two fingers' breadth above the tip of the medial malleolus The wounds of entrance and exit of the Steinmann pin are dressed with plain gauze bandage and a plaster of Paris boot is applied from the toes to within five inches of the knee joint incorporating the projecting ends of the pin in the cast The stirrup portion of the apparatus is then attached to the ends of the Steinmann pin and is held to the plaster cast by an additional turn of plaster bandage The lever arm attached to the traction stirrup is then fixed to the well leg splint and screw traction is

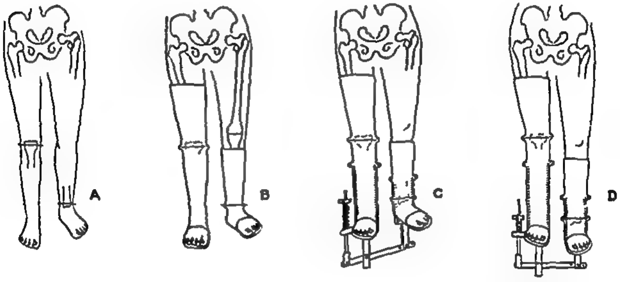


Fig 59 Well leg countertraction apparatus (*A*) A transfixion pin is inserted just above the malleoli on the affected side If desired a pin may also be inserted below the condylar flare on the well side though this is not essential (*B*) A short plaster of Paris boot to below the knee incorporating the transmalleolar pin is applied on the affected side A long plaster of Paris cast extending well up on the thigh with the knee in extension is applied to the well leg (*C*) The short stirrup is attached to the transmalleolar pin and incorporated in the plaster boot The long stirrup with the transverse lever arm and the screw attachment is incorporated in the long plaster cast on the well leg The lever arm is then attached to the short boot (*D*) By means of the screw on the well side traction is exerted until the fracture is reduced

made on the affected limb until the legs are parallel and the lever arm is perpendicular to the axis of the leg (Fig 59) The accuracy of the reduction must be checked by x-ray examination and the screw traction modified to increase or decrease its pull depending on the character of the reduction The patient may be permitted to sit up in bed and even in a wheel chair within forty-eight hours of the application of the apparatus Beyond occasional check by the x ray to determine the position of the fragments, no treatment is necessary until removal of the traction is decided upon

OPEN REDUCTION AND INTERNAL FIXATION

Open reduction of fractures has the merit of permitting firm fixation of the fracture site By permitting relatively early use of the neighboring joints, stiffness from

arm is supported in a sling and motion is started Buck's extension strips are attached to the forearm and a six-pound weight is suspended over a pulley so elevated that the forearm is flexed to about thirty-five degrees from the fully extended position of the arm To prevent upward displacement of the entire arm, a counterweight of about three pounds is suspended from a sling around the upper fragment of the humerus There is little danger of relaxation of the ligaments about the elbow because the actual reduction is mediated through the action of the olecranon against the lower fragment of the humerus (Fig 57)

Well-leg Countertraction Method

Anderson's well-leg countertraction method has especial application in fractures involving the lower extremity and may be used in certain fractures of the pelvis not otherwise amenable to closed treatment The method involves the use of a special traction device (Fig 58) A long leg plaster of Paris cylinder is applied to the opposite unaffected leg The splint against which traction is exerted by the

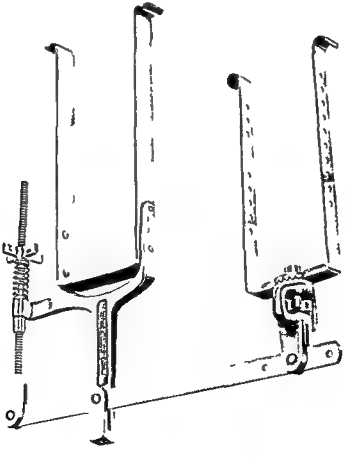


Fig 58 Well leg countertraction apparatus The shorter stirrup is for attachment to the Steinman pin that is inserted into the affected leg The longer stirrup is used to effect countertraction on the well leg (Courtesy of Dr Roger Anderson)

the plates must be fixed to the bone through previously made drill holes, the diameter of which is slightly less than the outside diameter of the screw or bolt To prevent burning of the bone and subsequent loss of rigid fixation, the rotary speed of the drill chuck should be reduced and the drill point should be cooled by frequent irrigations with saline Both cortices must be perforated and the screw or threaded bolt must be inserted directly in the path of the drill hole

While the threaded bolt and nut may be inserted at any desired angle in relation to the line of fracture, the screw should be inserted at right angles to the fracture line The length of the screw to be used should be measured and should be just

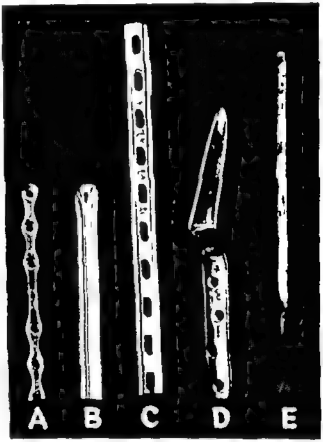


FIG 60 Metallic fixation devices (*A*) Lane plate (*B*) Smith Petersen triflanged nail (*C*) Eggers type plate (*D*) Blount Moore angulated blade plate (*E*) Parham band

sufficient to engage and penetrate the opposite cortex In short, oblique fractures one or more screws usually suffice for firm fixation In long oblique fractures with relatively little displacement fixation may be obtained by multiple screws or by encirclement with heavily chromicized catgut kangaroo tendon steel wire, or the metallic Parham band Since encirclement may lead to direct pressure necrosis of the bone as well as to localized circulatory impairment fixation in these cases as well as in transverse and certain severely comminuted fractures of the shaft preferentially may be obtained by the use of metallic plates

Usually straight these plates are available in different shapes for different types of fractures and afford convenient and excellent means of internal immobilization Occasionally the excessively firm fixation that these plates assure has been considered responsible for delayed union or nonunion by preventing bone-to bone contact during the period of resorption of the adjacent fractured surfaces To obviate

capsular contracture and muscle atrophy is avoided and relatively rapid functional rehabilitation of the limb and the patient as a whole can be effected. Open reduction has the disadvantage, on the other hand, that a simple fracture is converted into an open, contaminated wound, at least potentially capable of becoming infected. Statistically, this likelihood is minimal and should be considered as less of a deterrent than is the cosmetic aspect of the end result.

A long ugly scar on the arm of a laborer is certainly not to be desired, but even a good-looking scar on the arm of a young lady should be scrupulously avoided if at all possible. Where there are no medical contraindications, the social status and the psychological response of the patient must be given adequate consideration. Where at all possible and practical, operation should be avoided, where unavoidable, the surgical incision should be so placed as to be as inconspicuous as possible. The routine use of operative intervention in fracture therapy, to the neglect of older, classic methods of closed reduction is to be deplored.

Generally speaking, open reduction is not indicated in children, except in such situations as the fracture dislocations of the humeral condyles. In adults operative intervention may be justified in (1) intraarticular fractures, where anatomical alignment is essential, (2) fractures of the shaft of long bones in which alignment cannot be obtained, or, having been accomplished, cannot be retained, (3) compound fractures, (4) pathological fractures of the long bones in which pain cannot be relieved by other means of immobilization, (5) fractures in which experience has demonstrated that delayed union or nonunion frequently occurs, and (6) fractures in which the general condition of the patient is such as to contraindicate bed rest for the period of time usually required to obtain union by closed methods.

Open reduction of fractures involves two distinct procedures (1) exposure of the fracture site and reduction of the fracture by either manual or traction methods and (2) fixation of the fracture site. Exposure of the line of fracture is accomplished preferably through muscle retracting incisions so planned as to avoid important neurovascular structures. Reduction is effected by manual traction using bone hooks or bone holding forceps, or by screw traction on the fracture table. While longitudinal axial alignment is usually readily achieved, particular care must be exercised to avoid torsional malalignment. Fixation of the reduced fragments may be obtained by (1) intercortical fixation, (2) intramedullary fixation, or (3) bone grafting.

Intercortical Fixation Devices

Various mechanical aids have been employed in the internal fixation of fractures (Fig 60). These devices usually are composed of SMO stainless steel or vitallium, which are electrolytically inert and may be left in the tissues permanently. They should be inserted in such positions as to afford adequate fixation and be easy of removal if complications necessitating their extraction should arise.

The simplest of these are Lane plates flanged nails of the type devised by Smith-Petersen, blade plates Parham bands, self-tapping screws, and threaded bolts and nuts. The last two devices may be hammered or screwed directly into bone but

The method should not be used, save as the last resort in fractures in children In adults it is especially useful in the treatment of persistent nonunion, in pathological fractures caused by neoplasms in multiple fractures, and in fractures with loss of bony substance At the onset infections in or about the fracture were considered contraindications to intramedullary fixation Recent experience with war fractures however, has demonstrated the fact that intramedullary nailing may be successfully undertaken in cases in which there is infection of the soft tissue about the wound or even a low grade osteitis within the bone, provided that adequate debridement with delayed closure of the wound is undertaken concomitant with the administration of appropriate antibiotics In instances of frank purulent osteomyelitis, the use of the intramedullary nail is contraindicated

The nail originally described by Kuntscher has since been supplanted by a number of different types of intramedullary nails specifically designed for the treatment of the different long bones (Figs 62 and 63) Proper use of any intramedullary nail depends upon careful selection with respect to its length in relation to the length of the bone as well as to the internal diameter of the medullary cavity of the bone into which the nail is to be inserted While it is possible to thread the various fracture fragments over the nail without exposure of the fracture site (blind nailing), as is done in European clinics a small incision over the fracture line immeasurably facilitates penetration and correct direction of the nail into the distal fragment Particular care must be exercised to avoid torsional malalignment

In the femur tibia and ulna, the intramedullary nail is probably best inserted from above downward after making a preliminary drill hole at the upper end of the bone In the radius and probably also in the humerus the nail is best inserted from below upward In the tibia the point of entrance of the nail should be at about the level of the tibial tubercle and the drill hole of entrance should be made obliquely so as to permit of parallel insertion of the nail into the medullary cavity

It is only natural that a method that eliminates the need for constant attention to traction which reduces the period of hospitalization and minimizes the danger of nonunion should have received such general approbation and use The method is however not without its limitations and should not be undertaken except in an operating room completely equipped for the management of all complications that may possibly arise Despite its obvious allure intramedullary nailing should be performed only for definite indications that cannot be met by more conservative closed methods

Bone Grafts

Bone grafts offer no special advantage over other methods of internal fixation in most long bone fractures but may be extremely valuable in fractures of the short bones in pathological fractures arising in association with benign tumors of bone, and in fractures where an actual loss of bony substance or nonunion has occurred Cortical bone grafts are best adapted to firm fixation of the fractured fragments but they have little osteogenic value since most of the cells ultimately die Cancellous bone grafts on the other hand have little stabilizing value but since their cells survive for the most part they possess great osteogenic capacities It is, therefore

this plates (Eggers) have been manufactured in which the screw holes are elliptical rather than round This allegedly permits some sliding of the fracture fragments and, therefore, end-to-end bony contact even during the period of bone resorption

Wherever possible the plate should be applied subperiosteally in such manner that the mid-point of the plate directly overlies the line of fracture The upper half of the plate should be fixed to the proximal fragment directly in its longitudinal axis The distal fragment is then held against the lower half of the plate in correct anatomical alignment by means of a bone holding clamp (Lowman clamp, Hey Groves forceps) The clamp is removed only after the plate has been firmly secured to the distal fragment by an adequate number at least two, of self tapping screws

In fractures in which one fragment is insufficiently long to permit the use of a straight metallic plate, but in which the distal fragment is not large enough to afford adequate purchase fixation of the smaller fragment may be achieved by the use of an angulated blade plate (Blount-Moore) This type of fixation has been used specifically in fractures at the upper and lower ends of the femur and in fractures at the upper end of the humerus

Intramedullary Fixation Devices

The treatment of severely comminuted or multiple fractures in the same bone may be extremely complicated and has lead to the development of the technic of in

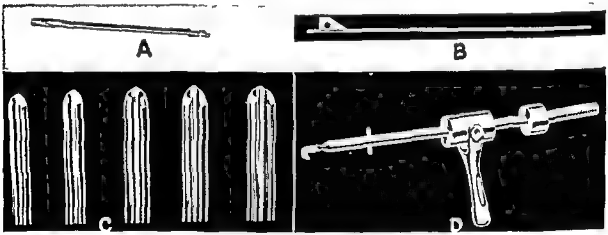


Fig 61 Kuntscher type of intramedullary nail (*A*) drill for reaming the intra medullary cavity (*B*) inserter (*C*) different sizes of nail (*D*) extractor (Courtesy of the Orthopedic Equipment Company)

tramedullary fixation Though this method had been described earlier it was popu larized during World War II by Kuntscher in Vienna (Fig 61)

The intramedullary nail method has the advantage of using a preformed anatomical channel for purposes of fixation It has acquired wide popularity since it reduces the period of necessary hospitalization and permits of earlier motion of neighboring joints While it does reduce the period of hospitalization it neither accelerates nor retards the biological rate of the repair process itself

The method should not be used save as the last resort, in fractures in children In adults it is especially useful in the treatment of persistent nonunion, in pathological fractures caused by neoplasms in multiple fractures, and in fractures with loss of bony substance At the onset infections in or about the fracture were considered contraindications to intramedullary fixation Recent experience with war fractures however has demonstrated the fact that intramedullary nailing may be successfully undertaken in cases in which there is infection of the soft tissue about the wound or even a low grade osteitis within the bone, *provided that adequate* debridement with delayed closure of the wound is undertaken concomitant with the administration of appropriate antibiotics In instances of frank purulent osteomyelitis the use of the intramedullary nail is contraindicated

The nail originally described by Kuntscher has since been supplanted by a number of different types of intramedullary nails, specifically designed for the treatment of the different long bones (Figs 62 and 63) Proper use of any intramedullary nail depends upon careful selection with respect to its length in relation to the length of the bone as well as to the internal diameter of the medullary cavity of the bone into which the nail is to be inserted While it is possible to thread the various fracture fragments over the nail without exposure of the fracture site (blind nailing), as is done in European clinics, a small incision over the fracture line immeasurably facilitates penetration and correct direction of the nail into the distal fragment Particular care must be exercised to avoid torsional malalignment

In the femur tibia and ulna, the intramedullary nail is probably best inserted from above downward after making a preliminary drill hole at the upper end of the bone In the radius and probably also in the humerus the nail is best inserted from below upward *In the tibia the point of entrance* of the nail should be at about the level of the tibial tubercle and the drill hole of entrance should be made obliquely so as to permit of parallel insertion of the nail into the medullary cavity

It is only natural that a method that eliminates the need for constant attention to traction, which reduces the period of hospitalization and minimizes the danger of nonunion, should have received such general approbation and use The method is however not without its limitations and should not be undertaken except in an *operating room completely equipped for the management of all complications that* may possibly arise Despite its obvious allure intramedullary nailing should be performed only for definite indications that cannot be met by more conservative closed methods

Bone Grafts

Bone grafts offer no special advantage over other methods of internal fixation in most long bone fractures but may be extremely valuable *in fractures of the short* bones in pathological fractures arising in association with benign tumors of bone, and in fractures where an actual loss of bony substance or nonunion has occurred Cortical bone grafts are best adapted to firm fixation of the fractured fragments but they have little osteogenic value since most of the cells ultimately die Cancellous bone grafts on the other hand have little stabilizing value but since their cells survive for the most part they possess great osteogenic capacities It is therefore

this, plates (Eggers) have been manufactured in which the screw holes are elliptical rather than round This allegedly permits some sliding of the fracture fragments and, therefore, end-to end bony contact even during the period of bone resorption

Wherever possible, the plate should be applied subperiosteally in such manner that the mid-point of the plate directly overlies the line of fracture The upper half of the plate should be fixed to the proximal fragment directly in its longitudinal axis The distal fragment is then held against the lower half of the plate in correct anatomical alignment by means of a bone-holding clamp (Lowman clamp, Hey Groves forceps) The clamp is removed only after the plate has been firmly secured to the distal fragment by an adequate number, at least two, of self tapping screws

In fractures in which one fragment is insufficiently long to permit the use of a straight metallic plate, but in which the distal fragment is not large enough to afford adequate purchase, fixation of the smaller fragment may be achieved by the use of an angulated blade plate (Blount-Moore) This type of fixation has been used specifically in fractures at the upper and lower ends of the femur and in fractures at the upper end of the humerus

Intramedullary Fixation Devices

The treatment of severely comminuted or multiple fractures in the same bone may be extremely complicated and has lead to the development of the technic of in

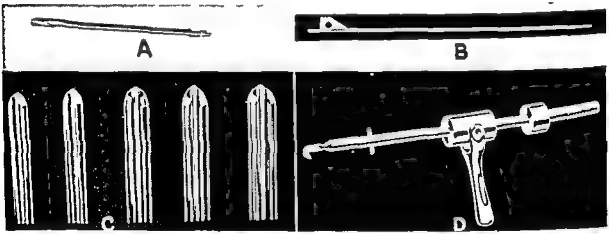


Fig 61 Kuntscher type of intramedullary nail (*A*) drill for reaming the intra medullary cavity (*B*) inserter (*C*) different sizes of nail (*D*) extractor (Courtesy of the Orthopedic Equipment Company)

tramedullary fixation Though this method had been described earlier, it was popularized during World War II by Kuntscher in Vienna (Fig 61)

The intramedullary nail method has the advantage of using a preformed anatomical channel for purposes of fixation It has acquired wide popularity since it reduces the period of necessary hospitalization and permits of earlier motion of neighboring joints While it does reduce the period of hospitalization it neither accelerates nor retards the biological rate of the repair process itself

The method should not be used save as the last resort, in fractures in children In adults it is especially useful in the treatment of persistent nonunion in pathological fractures caused by neoplasms, in multiple fractures, and in fractures with loss of bony substance At the onset, infections in or about the fracture were considered contraindications to intramedullary fixation Recent experience with war fractures, however has demonstrated the fact that intramedullary nailing may be successfully undertaken in cases in which there is infection of the soft tissue about the wound or even a low grade osteitis within the bone, provided that adequate debridement with delayed closure of the wound is undertaken concomitant with the administration of appropriate antibiotics In instances of frank purulent osteomyelitis the use of the intramedullary nail is contraindicated

The nail originally described by Kuntscher has since been supplanted by a number of different types of intramedullary nails specifically designed for the treatment of the different long bones (Figs 62 and 63) Proper use of any intramedullary nail depends upon careful selection with respect to its length in relation to the length of the bone as well as to the internal diameter of the medullary cavity of the bone into which the nail is to be inserted While it is possible to thread the various fracture fragments over the nail without exposure of the fracture site (blind nailing), as is done in European clinics a small incision over the fracture line immeasurably facilitates penetration and correct direction of the nail into the distal fragment Particular care must be exercised to avoid torsional malalignment

In the femur tibia, and ulna, the intramedullary nail is probably best inserted from above downward after making a preliminary drill hole at the upper end of the bone In the radius and probably also in the humerus, the nail is best inserted from below upward In the tibia the point of entrance of the nail should be at about the level of the tibial tubercle and the drill hole of entrance should be made obliquely so as to permit of parallel insertion of the nail into the medullary cavity

It is only natural that a method that eliminates the need for constant attention to traction which reduces the period of hospitalization and minimizes the danger of nonunion should have received such general approbation and use The method is however not without its limitations and should not be undertaken except in an operating room completely equipped for the management of all complications that may possibly arise Despite its obvious allure intramedullary nailing should be performed only for definite indications that cannot be met by more conservative closed methods

BONE GRAFTS

Bone grafts offer no special advantage over other methods of internal fixation in most long bone fractures, but may be extremely valuable in fractures of the short bones in pathological fractures arising in association with benign tumors of bone and in fractures where an actual loss of bony substance or nonunion has occurred Cortical bone grafts are best adapted to firm fixation of the fractured fragments but they have little osteogenic value since most of the cells ultimately die Cancellous bone grafts on the other hand have little stabilizing value but since their cells survive for the most part they possess great osteogenic capacities It is, therefore

this plates (Eggers) have been manufactured in which the screw holes are elliptical rather than round This allegedly permits some sliding of the fracture fragments and, therefore, end-to end bony contact even during the period of bone resorption

Wherever possible, the plate should be applied subperiosteally in such manner that the mid point of the plate directly overlies the line of fracture The upper half of the plate should be fixed to the proximal fragment directly in its longitudinal axis The distal fragment is then held against the lower half of the plate in correct anatomical alignment by means of a bone holding clamp (Lowman clamp Hey Groves forceps) The clamp is removed only after the plate has been firmly secured to the distal fragment by an adequate number, at least two, of self tapping screws

In fractures in which one fragment is insufficiently long to permit the use of a straight metallic plate, but in which the distal fragment is not large enough to afford adequate purchase, fixation of the smaller fragment may be achieved by the use of an angulated blade plate (Blount Moore) This type of fixation has been used specifically in fractures at the upper and lower ends of the femur and in fractures at the upper end of the humerus

Intramedullary Fixation Devices

The treatment of severely comminuted or multiple fractures in the same bone may be extremely complicated and has lead to the development of the technic of in

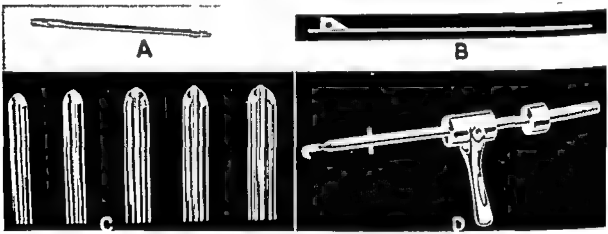


Fig 61 Kuntscher type of intramedullary nail (*A*) drill for reaming the intra medullary cavity (*B*) inserter (*C*) different sizes of nail (*D*) extractor (Courtesy of the Orthopedic Equipment Company)

tramedullary fixation Though this method had been described earlier, it was popu larized during World War II by Kuntscher in Vienna (Fig 61)

The intramedullary nail method has the advantage of using a preformed ana tomical channel for purposes of fixation It has acquired wide popularity since it reduces the period of necessary hospitalization and permits of earlier motion of neighboring joints While it does reduce the period of hospitalization, it neither accelerates nor retards the biological rate of the repair process itself

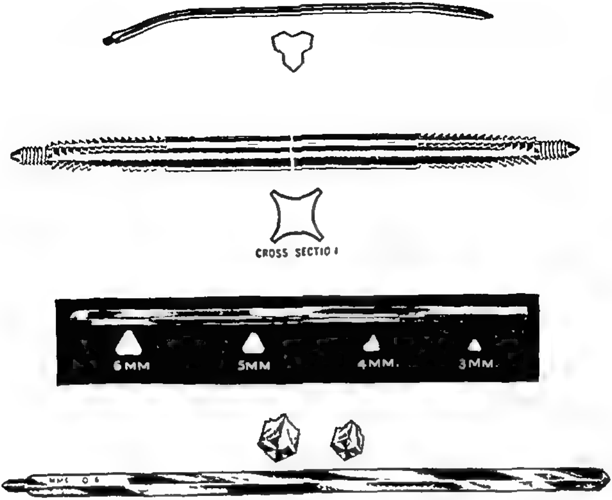


FIG 63 Different types of intramedullary nails First shown the Lottes nail particularly adapted for fixation of tibial fractures Second the Schneider four flanged intramedullary nail Third the triangular vom Saal intramedullary nail in sizes suitable for humerus radius and ulna Fourth the diamond shaped Hansen Street nail (Courtesy of Zimmer Manufacturing Company)

frequently desirable to use a combination of both of these methods, either alone or in conjunction with other metallic fixation devices

Cortical bone grafts may be derived from autogenous homologous, or antigenically inactivated heterologous bone but cancellous grafts are best derived from autogenous sources Autogenous bone from the tibia may be used to achieve both types of graft in a single specimen When taken, however, it is important that the crest of the tibia be left intact lest fracture of the tibia occur at the donor site (Fig 64) In addition, pain that is annoying and frequently persistent in the donor site and cosmetic disfigurement of the leg make this source less desirable than the iliac crest where abundant amounts of cancellous bone can be obtained with minimal difficulty and discomfort Cancellous bone is more abundant in the region of the

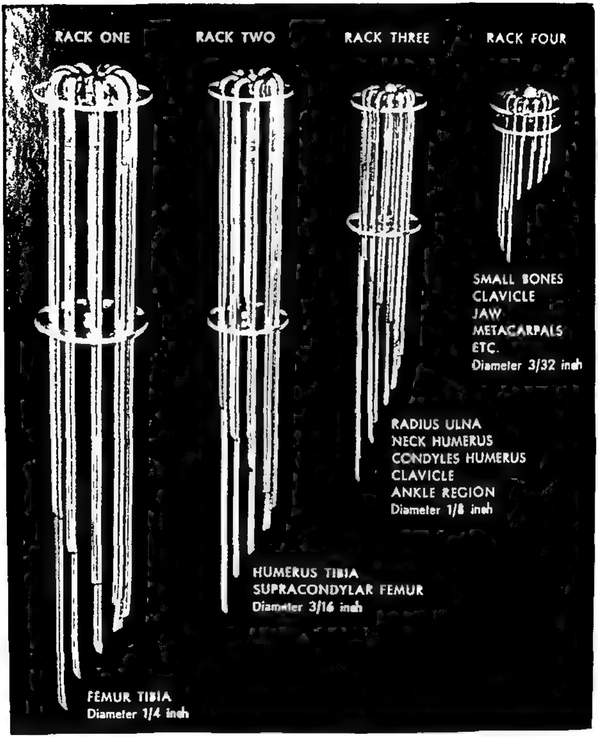


FIG 62 Rush type of intramedullary nail (Courtesy of the Berivon Company)

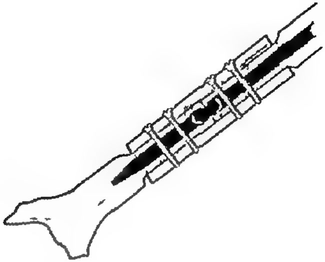


FIG 65 Onlay bone graft Either a single or a double onlay graft may be used The surface to which the graft is to be applied should be made flat by an osteotome The screws for fixing the onlay graft to the host site should be sufficiently long to engage the opposite cortex of the host or of the second onlay graft

osteotome to obviate any bone necrosis that might arise as a result of burning from the use of a saw The medullary cavity is then freed of scar tissue and the graft is firmly fixed to the bleeding surface of the host bone by means of self tapping screws that should engage the graft and both cortices of the host bone (Fig 65)

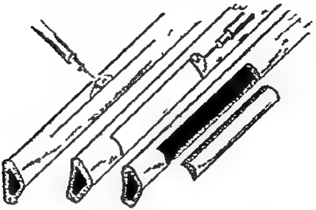


FIG 64 Method of obtaining cortical bone graft A single or double bladed saw may be used to obtain a section of the cortical bone from the tibia The tibial crest should be avoided so as to minimize the danger of subsequent *fracture of the donor bone* The bed *for im*plantation should be made narrower by the thickness of the saw blade to allow of snug apposition of the graft

posterior than in the anterior superior iliac spine though either may be used Ideally a segment of only the outer table of bone should be removed subperiosteally preferably en masse and care should be taken to suture the overlying muscles to the margins of the surgical defect in the ilium Cancellous bone thus obtained is packed subperiosteally into all the interstices between the cut ends of the fractured bone

Several different methods of cortical bone grafting have been employed but all are basically either (1) inlay grafts or (2) onlay grafts Inlay grafts involve the preparation of a host bed in either fragment of bone by the use of a double bladed rotary or reciprocating saw The bone graft may be obtained from the tibia or bone bank and should be of sufficient width to fit the host bed snugly To assure this the distance between the two parallel saw blades should be made slightly larger in cutting the graft than in preparing the host site If this is not done the graft will be narrower than the host area by the thickness of the saw blades and will require fixation to the host area by self-tapping screws which should be long enough to engage the cortex of the graft as well as the opposite host cortex

This type of inlay graft even with screw fixation has not proved as satisfactory as the massive single or double onlay type of graft used alone or in conjunction with metallic plating (Fig 202) Before applying the onlay graft a wide flat bed on the surface of the adjacent cortices of the fractured fragments is prepared using a broad

The designation "plaster casts" is, in fact, a misnomer The basic material used in the preparation of a cast is plaster, but the completed cast itself is not plaster, but gypsum The distinction is of more than pedantic importance, for the difference between the two products defines precisely the basic mechanism in both plaster manufacture and plaster setting

When water is added to plaster, setting occurs and gypsum is formed

$$\underset{\text{(plaster)}}{CaSO_4 \cdot \tfrac{1}{2}H_2O} + 1\tfrac{1}{2}H_2O \rightleftharpoons \underset{\text{(gypsum)}}{CaSO_4 \cdot 2H_2O}$$

The reverse reaction involving the heating of naturally occurring gypsum represents the basic process in plaster manufacture

Although it does represent what are believed to be the basic reactions, this simplified version is however, far from a complete picture of the chemical events involved At one time or another, owing in part to confusion in attempts at correlating the various observed properties of gypsum and its dehydration products, several other varieties of compounds have been recognized $CaSO_4 \cdot 2H_2O$ $CaSO_4 \cdot \frac{1}{2}H_2O$ and $CaSO_4$, and at least two forms of the dihydrate, three forms of the hemihydrate, and four different anhydrites have been postulated or allegedly described Crystallographically, however, no such array of varieties has been identified

More recently six substances in the calcium sulphate-water system have been found to have characteristic crystallographic patterns and unique and reproducible thermodynamic properties one dihydrate, two hemihydrates, two soluble anhydrites and one insoluble anhydrite

Calcium Sulphate Dihydrate ($CaSO_4 \cdot 2H_2O$)

The dihydrate occurs in nature either as the fine grained compact mass of crystals known as gypsum or as large transparent crystals called selenite Both varieties have the same thermodynamic properties and the same monoclinic prismatic crystal form The crystal contains four to eight molecules in the unit cell with layers of calcium atoms and sulphate groups separated by sheets of water molecules The water molecules occupy important positions in the crystal lattice and all the dehydration products of the naturally occurring dihydrate have distinctly different x ray powder diffraction patterns Thus dehydration involves not merely the physical removal of water but the actual destruction of the characteristic crystal lattice itself

Calcium Sulphate Hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$)

The hemihydrate is the only lower hydrate of calcium sulphate whose identity has been established with any degree of certainty The crystal is a deformed monoclinic form with twelve molecules in the unit cell It possesses great stability since the calcium atoms and sulphate groups are arranged in such a manner that strong forces exist between the calcium atoms of one layer and the sulphate groups of adjacent layers Water molecules exist in channels within the lattice but the distances are greater and hence the forces less between water and the $CaSO_4$ molecules than between Ca and SO_4 radicals Thus it is not surprising that in calcium sulphate hemihydrate in contradistinction to calcium sulphate dihydrate at least part of the water within the crystal can be removed without resulting in the destruction of the

CHAPTER 7

Plaster of Paris

Splints for the relief of pain and immobilization of fractures were employed as far back as we have knowledge, and the earliest of medical records testify to the great attention given to the perplexing problems presented by the aftermath of skeletal trauma Bandages stiffened with various gums and clays were probably the first means of skeletal immobilization Hippocrates evidently used bandages smeared with cerate and resin and in the Middle Ages barber-surgeons were well versed in the egg-white technics long used to saturate cloths that were to be wound securely about fractured extremities

Although plaster had been extensively used as construction material by the earliest of known civilizations (and had even been used by the inhabitants of the Tigris and Euphrates valleys to enclose broken limbs) the use of plaster per se, did not enter the medical armanentarium until the nineteenth century Hubenthal in France first used plaster of Paris to mold solid casts of extremities with reduced fractures It was not however until the conclusion of the Crimean War that there was a general knowledge of plaster of Paris bandages

In 1852 Matthysen a medical officer in the Dutch army, described a light yet durable plaster splint expressly for the immobilization of war fractures The basic principles had been elaborated some twenty years previously by Baron Suetin senior medical officer of the Belgian army who had described a starched apparatus consisting of cotton pads bandages and pasteboard splints impregnated with starch Combining the technics of Suetin and Hubenthal, Matthysen s first plaster of Paris bandage was composed of a coarse-meshed cotton material into the interstices of which plaster had been rubbed As such it was essentially identical with the plaster dressings now in use

Chemistry of Plaster

Despite many advances in the manufacture of plaster bandages over the past century very little has been added to knowledge of the detailed structure and thermodynamic properties of plaster

The designation plaster casts is, in fact, a misnomer. The basic material used in the preparation of a cast is plaster, but the completed cast itself is not plaster, but gypsum. The distinction is of more than pedantic importance, for the difference between the two products defines precisely the basic mechanism in both plaster manufacture and plaster setting.

When water is added to plaster, setting occurs and gypsum is formed

$$\underset{\text{(plaster)}}{CaSO_4 \cdot \tfrac{1}{2}H_2O} + 1\tfrac{1}{2}H_2O \rightleftharpoons \underset{\text{(gypsum)}}{CaSO_4 \cdot 2H_2O}$$

The reverse reaction, involving the heating of naturally occurring gypsum, represents the basic process in plaster manufacture.

Although it does represent what are believed to be the basic reactions, this simplified version is, however, far from a complete picture of the chemical events involved. At one time or another, owing in part to confusion in attempts at correlating the various observed properties of gypsum and its dehydration products, several other varieties of compounds have been recognized. $CaSO_4 \cdot 2H_2O$, $CaSO_4 \cdot \tfrac{1}{2}H_2O$ and $CaSO_4$, and at least two forms of the dihydrate, three forms of the hemihydrate and four different anhydrites have been postulated or allegedly described. Crystallographically, however, no such array of varieties has been identified.

More recently, six substances in the calcium sulphate-water system have been found to have characteristic crystallographic patterns and unique and reproducible thermodynamic properties: one dihydrate, two hemihydrates, two soluble anhydrites, and one insoluble anhydrite.

Calcium Sulphate Dihydrate ($CaSO_4 \cdot 2H_2O$)

The dihydrate occurs in nature either as the fine grained compact mass of crystals known as gypsum or as large transparent crystals called selenite. Both varieties have the same thermodynamic properties and the same monoclinic prismatic crystal form. The crystal contains four to eight molecules in the unit cell with layers of calcium atoms and sulphate groups separated by sheets of water molecules. The water molecules occupy important positions in the crystal lattice and all the dehydration products of the naturally occurring dihydrate have distinctly different x ray powder diffraction patterns. Thus dehydration involves not merely the physical removal of water but the actual destruction of the characteristic crystal lattice itself.

Calcium Sulphate Hemihydrate ($CaSO_4 \cdot \tfrac{1}{2}H_2O$)

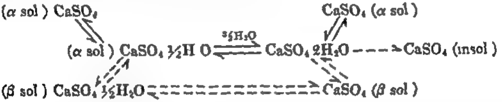
The hemihydrate is the only lower hydrate of calcium sulphate whose identity has been established with any degree of certainty. The crystal is a deformed monoclinic form with twelve molecules in the unit cell. It possesses great stability since the calcium atoms and sulphate groups are arranged in such a manner that strong forces exist between the calcium atoms of one layer and the sulphate groups of adjacent layers. Water molecules exist in channels within the lattice but the distances are greater and hence the forces less between water and the $CaSO_4$ molecules than between Ca and SO_4 radicals. Thus it is not surprising that in calcium sulphate hemihydrate in contradistinction to calcium sulphate dihydrate at least part of the water within the crystal can be removed without resulting in the destruction of the

crystal lattice Moreover, the hemihydrate can accommodate greater or lesser amounts of water than required by the formula without serious alteration in the crystal structure

A stable form of the hemihydrate alpha hemihydrate is produced when the dihydrate is placed in a nearly saturated steam atmosphere When this does not prevail or when the dihydrate is dehydrated in a vacuum at about 100 C a less stable compound beta hemihydrate possessing definitely different properties is produced Casting plasters are virtually exclusively of the alpha variety, whereas wall plasters contain relatively large amounts of the beta hemihydrate

Anhydrous Calcium Sulphate (CaSO)

Three forms of anhydrous calcium sulphate have been recognized insoluble (natural) anhydrite alpha soluble anhydrite and beta soluble anhydrite The latter two are further dehydration products of alpha hemihydrate and beta hemihydrate Insoluble anhydrite has the most stable atomic arrangement of any of the calcium sulphates but fails to take up water at any appreciable rate and probably plays no important role, if any at all in casting plaster



Thus plaster of Paris consists largely of calcium sulphate alpha hemihydrate containing greater or lesser amounts of water than required by the formula and some minor quantities of the anhydrites When placed in water plaster undergoes a characteristic change known as setting which is chemically characterized by the formation of calcium sulphate dihydrate or gypsum Dependent upon the surrounding atmosphere and temperature the gypsum cast in turn may partially dry yielding greater or lesser proportions of anhydrite crystals among the characteristic calcium sulphate dihydrate crystals of the cast

Plaster Bandage

Originally plaster bandages were made by dusting powdered plaster of Paris on cut strips of crinoline and rolling up the material thus prepared to form a bandage roll which was later wet and applied The bandages were fairly cheap to prepare and accordingly it was the custom for private physicians and hospitals to prepare their own plaster dressings The rolls had to be wound fairly tightly to obviate excessive loss of plaster from the dry roll during storage and handling and consequently, they were slow to wet did not wet uniformly and almost never wet completely A rather considerable amount of plaster was lost during this process and the entire procedure was somewhat less than pleasant for the surgeon and much less than aesthetic for the patient Owing to the long wetting time the resulting cast required a slow setting type of plaster and relatively long periods of time for setting This not infrequently made maintenance of the postreduction position of the fractured fragments a somewhat tedious and not always successful task

Retarder substances such as animal hairs, were frequently used to prevent setting from occurring during the time of application of the plaster bandages Crystalline *accelerator* substances, such as salt or gypsum itself, were often added to seed the gypsum mass of the cast and hence to increase the rate at which setting progressed immediately after the plaster bandages had been applied Unless performed with considerable care, however the resulting cast frequently was laminated and weak and tended to flour or onion skin

Commercially available hard coated bandages overcame some of the disadvantages of these loose-coated dressings These are currently in general use and are composed of crinoline or open mesh starch size gauze, which is coated with a slurry of powdered plaster They contain set-controlling agents and a material that binds the plaster in the dry state to the gauze The bandage has the advantage that the plaster is directly adherent to the fabric, is readily and uniformly wettable in a few seconds has a low plaster loss, and permits of the preparation of a stronger cast with a predictable and controllable setting time In contradistinction to the earlier homemade loose-coated plaster bandages, when water is expressed from hard-coated bandages, little water remains in excess of that required (about 21 per cent) to hydrate the plaster to form gypsum, and hence optimum cast strength may be obtained

The crinoline or gauze contributes little or no additional strength to the cast in ordinary hard-coated bandages and serves solely the function of conveying wet plaster to the extremity or trunk to be immobilized Hospital crinolines usually are three, four or six inches wide although other widths are also commercially available The fabric has thirty-two by twenty-eight threads per square inch in most bandages marketed today, though some firms also prepare crinolines or gauze with twenty-eight by twenty-four threads per square inch

Two general types of bonding agent are used in hard-coated bandages One is a so-called dry binder such as methyl cellulose, that is water-soluble and has little or no bonding action save in the dry state The wet binder is a water-insoluble material exemplified by polyvinyl acetate that both assists in holding the plaster on the dry bandage and prevents excessive loss of plaster when the roll is squeezed out after wetting

The slurry of powdered plaster is applied to the gauze, dried out and cut to desired proportions by machine Early manufacturing procedures used a slurry in an organic liquid such as acetic acid or 95 per cent alcohol in order to avoid aqueous slurry solvents that would cause the plaster to set during manufacture More recently the plaster slurry is made in water containing 1 to 2 per cent ammonium borate, which prevents setting of the plaster As the water is dried from the coated gauze the ammonium borate decomposes with the liberation of ammonia so that there is no interference with the set of the plaster in the finished product

The setting time of most hard coated plaster bandages is controlled by a material such as potassium sulphate or freshly ground gypsum Occasionally set inhibitors such as sodium citrate are incorporated into the plaster

Until a few years ago the plaster commonly used in plaster bandages had been what is known as a low density high consistency plaster (high consistency in that

a relatively large proportion of water was required in order to obtain a free flowing plaster water slurry) At the present time, the best plasters are high density, low consistency in which little excess water is required to obtain a soft mixture of plaster Consequently, less water is present in the resulting gypsum cast, the cast is of denser structure and is stronger

Recently a considerable improvement in plaster bandages has been accomplished through the incorporation of a water-insoluble melamine-formaldehyde resin in the bandage with the plaster The resin is cold-setting and in the presence of a catalyst, polymerizes, as the plaster is setting and the cast drying to bond the gypsum particles to each other and to the gauze backing The resulting cast is essentially a structural unit much like Hubenthal s original solid plaster of Paris cast in which both the gypsum and the gauze contributed to the ultimate strength of the cast The resin-polymer-gypsum combination thus produces a cast of tremendously increased strength per unit mass as compared with casts produced from ordinary hard coated plaster bandages The melamine plasters may either be prepared as such or by dipping ordinary hard-coated plaster bandages into an aqueous solution of the resin rather than wetting the plaster in ordinary water

In addition to possessing the advantages of increased strength per unit mass and hence the desirable attribute of being lighter for equivalent tasks, casts made from melamine formaldehyde plasters demonstrate some slight antibacterial activity owing to their formaldehyde content They also have the decided advantage of being relatively immune to the deleterious softening and weakening effects of moisture, water and urine, since the resin becomes water-insoluble as it polymerizes

Against these advantages however are the disadvantages that the resin plaster bandages are somewhat more expensive than ordinary plaster bandages, have a somewhat greater tendency during storage to be adversely affected by excessive heat and moisture and in clinical practice, may occasionally be responsible for various cutaneous hypersensitivity phenomena as a consequence of their formaldehyde content

Application of Plaster of Paris

Plaster of Paris splints may be made from commercially available plaster slabs function is immobilization either of the parts of a single bone as after a fracture or of the joint between two bones It may also be employed in the correction of slight axial malalignments in the prevention and treatment of soft tissue contractures across joints or paradoxical as it may superficially appear in increasing mobility of a joint

In fractures classical practice dictates that the plaster cast be of sufficient extent to incorporate both the joint above and the joint below the site of fracture For adequate immobilization of a joint the cast must be sufficiently extensive to secure a firm hold on both the proximal and distal bones and should incorporate at least half the total length of each of the bones Immobilization may be obtained by use of plaster splints or cylinders The other functions of plaster can only be subserved by the construction of cylinders since plaster splints do not permit of wedging or of the application of elastic force

Skin Preparation

Preparation of the skin prior to cast immobilization should be limited in closed fractures to careful washing of the skin surface, preferably with a surface acting detergent, followed by careful drying of the area to be encased in the cast In most instances, other procedures, such as the application of benzoin or other adhesive compounds, serve no useful function and may, by affording a mechanical barrier to sweat and sebaceous gland secretions, give rise to undesirable side effects

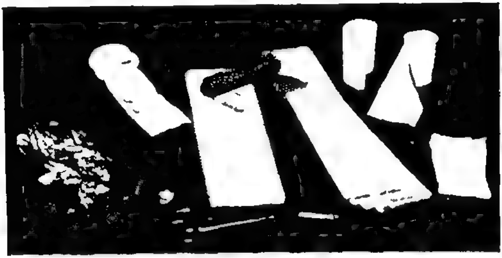


Fig 66 Materials used in the application of plaster In the upper left hand corner stockinette for encasing the limb, on the right candy cotton roll and felt for padding of the bony prominences in the center plaster slabs and rolled plaster bandage with wire mesh and basswood splints for reinforcing the plaster Rubber gloves lower left hand corner may be used to protect the hands of the surgeon

Plaster of Paris may be used in the form of slabs or splints or as cylindrical molds

Plaster of Paris splints may be made from commercially available plaster slabs or by unrolling and layering an ordinary plaster bandage The latter method has the advantage of permitting splints to be made of any desired length Both are hydrated by immersion in warm water and are then faced with a thin layer of felt or candy cotton to protect the skin against which the splint is to be applied (Figs 66 and 67) The splint is then laid against the part to be immobilized and is held in the desired position by means of ordinary gauze bandage until setting has occurred When setting is complete the splint is removed trimmed as needed and thoroughly dried When dried, the margins of the splint should be carefully bound with adhesive tape to protect the skin against injury from the sharp edges of the dried plaster The splint is then reapplied and held in place by encircling elastic bandages

Many surgeons insist upon immobilization in certain types of fractures, particularly Colles fractures by splints secured to the forearm in this fashion While this procedure is unquestionably safer in that it minimizes the possibility of circulatory

impairment, it is frequently unsatisfactory in that splints do not completely immobilize the fractured fragments and often require greater skill in their application than need be displayed in the reduction of the fracture itself Splints are definitely weaker than encircling plaster molds and their use completely precludes the possibility of change in position by wedging for the correction of any persistent malalignment They are, however, invaluable for the support of a part where loss of position need not be feared

Circular plaster of Paris molds afford greater stability for immobilization but, when used in acute fractures, may entail the risk of circulatory impairment Persistence of pain, numbness of the distal parts, cyanosis or blanching of the skin, and swelling are all indicative of circulatory embarrassment The consequence of failure

Fig 67 Preparation of a plaster slab by unrolling and layering of a plaster of Paris bandage may be done with either a wet or a dry bandage

to recognize and institute early and energetic treatment of diminished peripheral blood flow is so devastating as to make retention of the fracture of only secondary importance The mold must be split immediately, discarded if necessary, and the limb must be placed in whatever position serves to re-establish its arterial supply While prophylactic bivalving of the plaster is essential in patients not under direct observation during the first few hours after reduction, it need not be made a routine if the patient can be observed and treated promptly upon the appearance of the earliest signs of circulatory distress After all immobilization is a necessary and important part of the care of a fracture It involves certain responsibilities in addition to that of reduction and those unwilling to accept all the responsibilities will probably sleep better if the care of the patient is turned over to another colleague

Padded and Nonpadded Casts

As a general principle it is desirable to afford some protection for the skin over bony prominences as a means of obviating cutaneous pressure necrosis Anxiety

on this score, however, has not infrequently led to the opposite, equally real danger of overpadding This should be avoided It must not be forgotten that the function of a cast in fracture therapy is immobilization of osseous structures that anatomically happen to be covered by a varying thickness of muscle, soft tissues, and skin The thicker the layer of tissue and padding interposed between the bone and the cast the less secure is the immobilization of the fractured fragments and the less certain the ultimate result Besides being unnecessarily wasteful, overpadding merely serves to render the osseous fixation less secure

It is because of this that some surgeons have advocated the use of the unpadded plaster of Paris cast This type of cast demands particular care in its application to avoid the formation of wrinkles that may cause pressure sores Plaster applied directly to the skin or over a thin layer of protective material without tension on the skin and with extraordinary care taken to have the inner-facing surface of the cast entirely free of ridges will not result in pressure necrosis even when applied over subcutaneous bone It is especially important to avoid indentation of such unpadded casts by pressure of the fingers When gently guided by the ball of the hand without traction, the plaster of Paris bandage may be rolled around prominences without fear of pressure sores and affords firmer fixation than can be obtained by the padded cast It ensures better grasp of the bone ends and considerably greater stability at the site of fracture than can otherwise be obtained though it does make for somewhat greater difficulty at the time of removal

Cast Padding

Three materials are customarily used in padding either the trunk or an extremity to be immobilized (1) stockinette, (2) sheet wadding or candy cotton, and (3) felt In general the first two materials are most widely used to protect larger surfaces, while felt is best adapted to protecting small bony prominences

Adequate protection without padding can be obtained by means of stockinette of adequate diameter (unstretched) and about six inches longer than the total extent of the parts to be immobilized Ordinary commercially available stockinette, a seamless usually unbleached tubular knit cotton fabric is sufficient, provided meticulous care is taken to avoid ridges and other irregularities on the inner surface of the cast

Thin felt or sheet wadding a thin uniform nonabsorbent cotton web lightly coated with starch affords additional padding without appreciably increasing the thickness of the total cast padding It should be wound about the part to be immobilized fairly snugly but not tightly, and may be held in place simply by tearing the end of the sheet wadding and placing the roughened middle surface of one layer upon the smooth surface of the immediately subjacent layer (Fig 68)

Thicker felt sheets or suitably cut felt rings may be placed either directly upon or about the bony prominences and held in place with adhesive tape For most other purposes, felt adds little in the way of protection and materially increases the likelihood of inadequate immobilization

FIG 68 Padding of leg for application of a plaster cast Stockinette has been applied to the level of the knee joint and beyond the toes A thin layer of felt has been wrapped about the upper end of the leg to protect the peroneal nerve and to prevent pressure on the head of the fibula Similarly, a thin layer of felt has been wrapped about the ankle joint to protect the malleoli and a single protecting layer of felt has been laid over the subcutaneous surface of the tibia

FIG 69 Wetting of the plaster bandage On removal from the water the plaster bandage is grasped at both ends and gently squeezed toward the center so as to prevent loss of plaster and telescoping of the bandage

WETTING OF THE PLASTER

Wetting or hydration of the plaster bandage is accomplished by complete submersion in a pail of water Whether placed on end or flat, the bandage should not be touched or the water stirred until all the bubbling caused by release of air in the bandage has ceased To remove the bandage from the water, it should be grasped at both ends and gently squeezed toward the center This avoids excessive loss of plaster and prevents telescoping while the bandage is being unrolled (Fig 69)

APPLICATION OF THE PLASTER

The plaster bandage should be gently guided around the part to be immobilized by the ball of the hand and should never be pulled into place by the fingers (Fig 70) With this guidance the bandage can be unrolled in any desired direction An abrupt change in the direction of the bandage should be accomplished by folding the bandage back upon itself without wrinkle

A well made plaster of Paris structure, whether a splint or a so called cast must be homogeneous and on cutting must present the appearance of a creamy cheese This can be accomplished only if each layer of the plaster is well rubbed as it is applied This serves to force the plaster of Paris through the meshes of the gauze and binds each layer of plaster to those immediately below it Failure properly to rub in each layer of plaster bandage results in a plaster structure that on cross section is laminated and has been described as being of the onion peel type This type of cast is distinctly weaker than the homogeneous type

The plaster structure must be completed within the time limit for setting of the plaster Setting varies with the type of plaster used, but may be expected to take place within five to twenty-five minutes The rapidity of setting may be accelerated

FIG 70 Application of plaster The bandage is unrolled by pushing with the ball of the hand and should never be lifted off the part being immobilized *One hand unrolls the plaster bandage while the other* hand rubs the layers already applied

by the addition of ordinary salt or increase in the temperature of the water used to wet the plaster Setting may be delayed by the addition of sugar or the use of cold water

SETTING OF PLASTER

Setting of plaster is due to the formation of gypsum crystals from the hydrated plaster of Paris It occurs suddenly and can be recognized by the change from a wet glistening surface to a dull white finish and the conversion of a soft into a hard sound when the cast is tapped with the finger or an instrument Even though setting has been completed the plaster is still wet and should not be submitted to any stress until entirely dry Drying of a plaster mold usually occurs within twenty-four hours but may take as long as several days Humid weather will necessarily delay drying Drying may be expedited by heating under a lamp or by the use of an electric fan to increase evaporation of the excess water in the plaster In thick casts drying may be so long delayed that removal and reapplication of another cast may be necessary

Reinforcement of Plaster Casts

Particularly in situations where the plaster crosses a joint, reinforcement may be necessary to avoid breaking the mold This may be effected by incorporation into the cast of strips of metal or wood previously steamed so as to permit conformation with the surface of the cast The drawback to the use of metal is that

Fig 71 Reinforcement of the plaster A plaster slab is laid along the lateral aspect of the mold to reinforce the cast as it crosses the ankle joint This gives maximal stability with minimal increase in the ultimate weight of the cast

Fig 72 Plaster bridging Where the cast has been weakened by removal of a window its strength may be restored by bridging the gap by one or more ropes of plaster that are fixed to the cast by circular plaster of Paris bandages

it frequently obscures the area to be x-rayed at a later time This may be obviated by the use of plaster slabs laid along the lateral aspect of the cast rather than in front so that they act as I beams to resist breaking stress (Fig 71) Where the reinforcement must cross the front of the joint or where it is desired to bridge a large gap in the plaster, the plaster slabs may be converted into a rope and laid across the joint or arched across the gap before being incorporated in the plaster (Fig 72)

For reasons already noted (Chap 2), a thin metallic marker such as a Kirschner wire or probe should be placed along the long axis of the plaster cast before the last turn of plaster is applied It is the only objective method for assuring the similarity of consecutive x rays and may be of the utmost importance in medico-legal matters (Fig 73) While still wet, the date of application of the plaster and

Fig 73 Insertion of radiopaque marker A probe has been fastened to the outer side of the plaster mold and incorporated in the plaster so that the identity of subsequent roentgenograms can be determined by the relationship of the shadow of the marker to that of the bones This is important in the estimation of apparent change in axial alignment in serial x rays

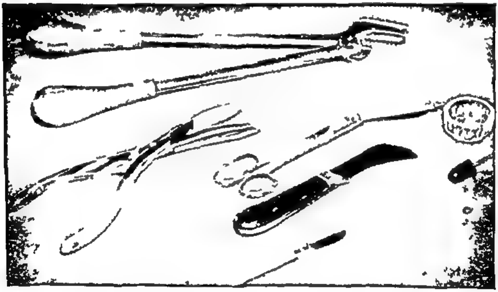


Fig 74 Instruments used in cutting or trimming plaster casts The Bard Parker blade the linoleum worker s knife and scissors are in the center To the right is a receptacle and medicine dropper for wetting the plaster To the left a duck bill for bending out the edges of a plaster cast and above the Stille cutter

the nature of the fracture should be outlined on the surface of the cast with an indelible ink pencil

Once it is completed the plaster of Paris mold should be trimmed to permit motion or examination of the circulation An old Bard-Parker blade is most useful while the cast is still wet a linoleum worker s knife when the cast is dry (Fig 74)

A plaster of Paris mold should be smooth and neat when completed The patient does not know what is going on under the plaster and it is a reassuring comment on the surgeons competence to note that attention has been given to binding the edges of the cast with adhesive plaster or to keeping the cast clean by a stockinette or a simple gauze bandage This, of course, thwarts the artistic propensities of the patient's visitors but is helpful to the surgeon who has noted important information on the surface of the plaster Painting with a thin film of shellac tends to water proof the plaster

If gloves have been used in the application of the plaster, they should be washed while still on the hands If no gloves have been used, washing the hands with a sugar paste removes the plaster from around the nails and leaves the surgeon s skin soft and smooth

Fenestration of Plaster Cast

It is frequently necessary to fenestrate the plaster for the purpose of dressing a wound or examining a painful skin area (Fig 75) The electric saw is efficient

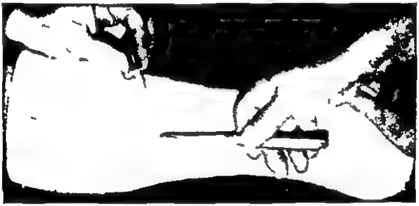


Fig 75 Cutting of the plaster cast The cast has been wet along a penciled line and is then cut along this line using a linoleum worker s knife

and timesaving but is fearsome to all children and to many adults With a little extra effort a window may be opened by cutting with a plaster knife along a penciled line previously moistened with plain water (Fig 76) Where skintight plaster has been applied particular care must be taken to avoid cutting the underlying skin Actual division of the layer of plaster next to the skin is betrayed by a characteristic hollow sound that results from cutting of the cross fibers of the gauze

The making of a window predisposes to the development of window edema (Fig 77) This can be combated by a pressure dressing or replacement of the excised portion of the cast Where it is desired to maintain a permanent opening in the cast for the treatment of a local condition while plaster immobilization is maintained, the strength of the cast may be restored by bridging the defect by one or more plaster of Paris ropes (Fig 72)

FIG 76 Fenestration of the cast The area to be freed is outlined with a pencil wet with water or acetic acid and cut down to the stockinette The stockinette should be cut separately and its edges turned back to line the margins of the window

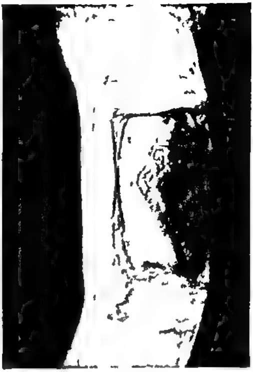


FIG 77 Window edema Following fenestration of the cast edema of the exposed tissues may occur This can be prevented either by a pressure dressing or by replacing and firmly fixing into place the plaster lid removed by fenestration

CUTTING OF PLASTER CAST

Splitting or bivalving of a plaster cylinder may be accomplished by the plaster knife, electric saw, or the Stille shears (Figs 78 and 79) Complete removal of a plaster cylinder especially in the lower extremities is almost invariably followed by swelling and cyanosis which is most distressing to the patient This results from

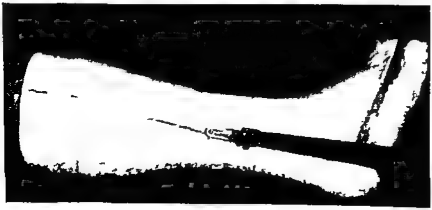


FIG 78 Splitting of the cast The cast has been wet and split along a previously penciled margin along the outer surface using either a knife electric saw or Stille shears

FIG 79 Bivalving of the cast By splitting the plaster along both its lateral and medial aspects the plaster cylinder may be converted into anterior and posterior splints The cast may be reconstituted by strapping the two halves together with adhesive tape or canvas straps

a loss of the vasomotor tone of the extremity and is readily overcome by the application of an Unna's paste boot or, more simply, by contrast bathing, gentle massage, or an elastic bandage

WEDGING OF PLASTER CAST FOR AXIAL MALALIGNMENT

The intact plaster mold may be used for the purpose of correcting axial malalignments Angulational malalignment may be corrected by wedging, which can be of two types the simple *axial* type or the *clamshell* type Axial wedging may be accomplished by the removal from the hemicircumference of the cast at the level of the plaster as hinges The distal portion of the cast is angulated toward the side the angle of axial deviation Small portions of the cast are left to act as hinges, beyond this the other hemicircumference is cut through, using the uncut portions of the plaster as hinges The distal portion of the cast is angulated toward the side from which the pie shaped sector was removed This closes the wedge on one side and at the same time converts the incised portion of the cast on the opposite side into a wedge-shaped opening (Fig 80)

Clamshell wedging is accomplished by making a single hinge in the plane in which it is desired to correct an angulation Circumcision of the whole circumference of the cast beyond the hinge permits angulation of the distal fragment toward the hinge, with the *opening* of a wedge in the line of the circumcision (Fig 81) *Removal of a wedge* of plaster in the line of circumcision permits angulation of the distal fragment in a direction opposite to the hinge Because of the greater distance that the circumcised portion of the cast must be moved to achieve any desired degree of angulation this method permits of greater leverage action and therefore of greater force in wedging of the underlying bone Torsional or transpositional malalignments may be corrected by complete circumcision of the plaster

at the level of the malalignment (Fig 82) Overriding may be corrected by the insertion of distracting turnbuckles Excessive distraction may be corrected by excision of a sleeve of plaster After the desired correction has been obtained, the integrity of the plaster cast should be re-established by several turns of plaster of Paris bandage

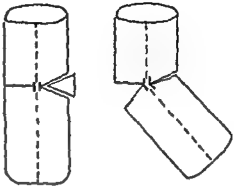


FIG 80 Axial wedging of the cast A crescentic section of the cast is removed from one hemicircumference leaving intact a small hinge both anteriorly and posteriorly The other hemicircumference is simply cut through The distal portion of the cast is then angulated toward the side from which the crescentic section was removed and the cast is reconstituted by replacing the excised portion in the wedge that has been opened A few turns of plaster of Paris bandage serve to complete the wedged cast

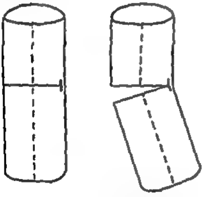


FIG 81 Clamshell wedging of a cast The entire circumference except for a small hinge is cut through and the cast is angulated toward the side on which the hinge remains The cast is reconstituted by several turns of plaster of Paris bandage

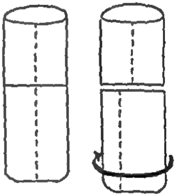


FIG 82 Correction of torsion The cast is completely circumcised at the level of correction The distal portion is then rotated to correct the torsional malalignment Several turns of plaster of Paris bandage serve to maintain the correction

MOBILIZATION OF JOINTS

For the correction of angulation existing between two bones the same type of axial wedging may be employed as in the correction of angulation *within a single* bone Considerable force may be exercised through the action of a Quengel apparatus This is made by applying a plaster cast to the proximal bone or portion of the extremity A cantilever of plaster wood or preferably metal is incorporated in the plaster and extends beyond the involved joint for a distance about equal to the length of the distal segment When the cast has set and the cantilever is firmly fixed, a sling is passed about the distal extremity and either by elastic traction or by

FIG 83 Quengel apparatus to overcome contractures A plaster of Paris cylinder is applied to the proximal portion of the angulation to be corrected A cantilever is incorporated in the plaster and a sling is placed around the distal portion of the angulation By means of a Spanish windlass or elastic traction the distal portion is pulled up to the level of the cantilever This serves to enforce passive motion in a single direction

FIG 84 Hinged cast To permit active motion prefabricated hinges are fixed to the plaster cast with the axis of motion of the hinge in the plane of motion of the joint A cuff of plaster is then removed

means of a Spanish windlass is pulled up against the projecting cantilever (Fig 83) To preserve motion elastic traction is to be preferred to fixed wedging

In the larger joints where it is desired to preserve motion, it is better to insert prefabricated metallic hinges into the plaster (Fig 84) After the hinges are fixed in place so that the axis of motion of the hinge corresponds with the axis of motion of the joint, the plaster cuff between the hinges is cut away so as to allow free

FIG 85 Hinged cast with elastic traction Hinges have been inserted into the plaster of Paris cast Brass curtain hooks have been attached to the plaster on either side of the joint By passing rubber bands across the hooks both in front of and behind the joint active flexion or extension across the joint may be assisted

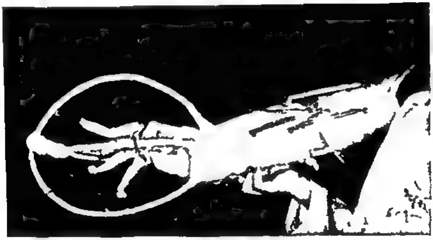


FIG 86 Hinged plaster cast with banjo splint A long arm cast has been hinged and fitted with elastic rubber band traction to encourage motion at the elbow A banjo splint has been incorporated in the arm cast to permit placing the wrist in dorsal extension Elastic traction has been applied to the banjo splint to permit straightening of the flexed fingers

motion of the joint Motion in both directions of the joint may be obtained by fixing brass curtain rod screws into the plaster cast on either side of the joint Rubber bands under tension are looped over the screws in sufficient number to achieve the desired effect (Fig 85) In the smaller joints, such as the wrist or the fingers, the distal portion of the plaster may be substituted for by a heavy wire incorporated in the proximal plaster to make a banjo frame to which the rubber bands are attached By suitably bending the wire any degree of force may be applied across the affected joint (Fig 86)

Types of Plaster Casts

For the primary purposes of immobilization certain types of plaster of Paris cylinders are standard

THE FOREARM CAST

In the treatment of fractures of the carpal bones and certain types of Colles fracture a short forearm cast to just below the elbow joint is frequently adequate In fractures of the bones of the forearm, however, or in Colles' fractures where

Fig 87 Short forearm cast The plaster is carefully molded in the palm so as to maintain the hollow of the palm To allow free motion of the fingers the cast should never extend distally beyond the proximal palmar crease To allow free motion of the thumb the cast should be cut well above the carpometacarpal joint level

the pain persists the immobilization must include the elbow joint and extend to the lower third of the humerus The wrist and dorsum of the hand should be lightly padded and the plaster rolled on without tension Particular care must be taken to maintain the hollow of the palm to avoid a flat hand (Fig 87)

Flat hand is more serious than flat foot and may result in far greater functional disability than failure satisfactorily to reduce the fracture Flat hand invariably results from abduction and external rotation of the thumb and can be prevented by molding the plaster into the hollow of the palm so that the thumb and fingers are held in the normal position of grasping Even when it is desired to immobilize the thumb as in the scaphoid cast this should be done in the position of function Except when it is specifically intended to immobilize the fingers in extension the plaster should never extend distally beyond the proximal palmar crease, so as to allow full motion of the fingers

THE FULL-ARM CAST

When it is desired to extend the short forearm cast beyond the elbow, the bony prominences about the elbow must be padded to prevent pressure necrosis of the skin Pressure over the antecubital region should be avoided and the crossing of the plaster bandage should occur behind rather than in front of the elbow This is especially the case when the elbow is fixed in flexion Except for special indications where the arm is immobilized in complete extension, the usual position for the application of a full arm cast is with the elbow in ninety degrees flexion and in mid-pronation of the forearm For adequate immobilization of the lower third of the

FIG 88 The full arm cast The plaster cast includes the elbow and may extend well up on the arm The elbow should be in ninety degrees of flexion with the forearm in mid pronation

humerus the cast must be extended well up into the axilla and may be immobilized against the trunk by a linen bandage or a plaster swathe (Fig 88)

THE HANGING CAST

The hanging cast method of treating fractures of the humeral shaft is based on the principle of traction in which the weight of the arm and its encircling plaster of Paris cast supplies the effective force With the elbow flexed to a right angle and the forearm in mid pronation, a circular plaster cast is applied from the level of the fracture down to the proximal palmar crease A loop of plaster is fashioned and incorporated in the cast at the level of the wrist When set, the plaster is suspended from the neck by a muslin bandage permitting the patient to be ambulant (Fig 89) The effectiveness of the traction depends upon the arm hanging down and it therefore imposes the necessity of sleeping in the seated position It is particularly valuable in elderly patients in whom prolonged bed rest, open operation or recumbency is feared

Though it has a definite place in the treatment of fractures of the upper humeral shaft it should not be employed routinely nor be permitted to supplant the more familiar methods of skin or skeletal traction In addition to the enforced sleeping in the seated position, it has other drawbacks It is difficult to control the traction force either to correct overriding or to prevent distraction Far more important

FIG 89 The hanging cast A long arm cast is applied with the elbow in flexion and the forearm in mid pronation A loop of plaster is made and attached to the radial side of the cast From this the cast may be suspended about the neck To maintain alignment an axillary wedge has been employed

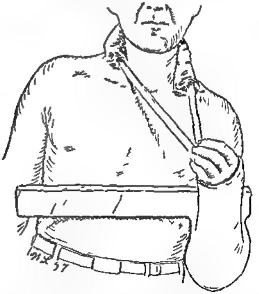


FIG 90 Modified hanging cast A medially projecting wing has been incorporated in the cast and abuts against the chest wall to prevent internal rotation of the distal fragment of the humerus (Reproduced from Milch H The winged hanging plaster *Bull Hosp Joint Dis* *8* 20 1947)

than this, however is the forced internal rotation that suspension from the neck imposes upon the distal fragment In short spiral fractures this in itself may act to cause interposition of soft tissue and so lead to nonunion In an effort to overcome this defect it has been suggested that a wing be incorporated into the plaster The wing resting against the chest wall does in fact prevent torsion but patients complain that even when well padded the wing is irritating and sometimes painful (Fig 90)

LEG CASTS

Leg casts are applied in the form of long or short plaster of Paris boots that usually include the foot The short plaster boot extends from below the knee joint to the toes with the ankle in the neutral position at ninety degrees (Fig 91) The malleoli the back of the heel and the dorsum of the foot must be adequately protected by padding Particular attention must be given to the protection of the peroneal nerve as it crosses the neck of the fibula Pressure against the upper edge of the boot may result in a dropped foot This can be prevented by careful padding or by cutting the cast down on its outer side so as to avoid direct pressure on the nerve The subcutaneous surface of the tibia should be protected by a single layer

FIG 91 Short leg cast The plaster boot extends from below the knee joint to the tips of the toes on the plantar surface of the foot The ankle is in the neutral position

of felt The plaster must extend to the tips of the toes on its plantar surface so as to prevent dropping of the toes On the dorsal surface of the foot, the cast may be cut back to the level of the metatarsophalangeal joint to permit observation and motion of the toes Wherever possible the longitudinal arch of the foot should be carefully preserved by molding of the plaster This should, however, not be attempted unless a footboard has been placed against the plantar surface of the foot to insure that the weight-bearing areas of the foot lie in the same plane (Fig 92)

There is nothing more distressing than an artistically molded foot plaster in which the outer or inner rays of the foot have been depressed and fixed so that weight bearing becomes impossibly painful after removal of the cast Weight bearing may be permitted in the short leg cast by incorporating a rubber heel or walking iron The rubber heel should be placed sufficiently far forward to maintain balance on the foot while walking usually in the plane of the anterior surface of the tibia The walking iron should be inserted slightly in front of the axis of the leg and should project sufficiently below the plantar surface of the cast to avoid contact of the front part of the cast with the ground when the knee is flexed in progression

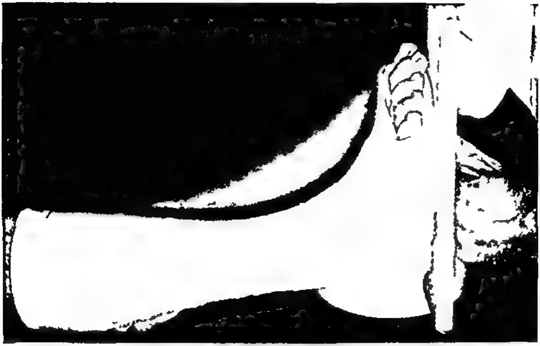


FIG 92 Use of footboard in leg casts Before the plaster has set solidly the use of a footboard applied to the plantar surface assures alignment of the hind foot and forefoot in their proper weight bearing relationship The arch on the inner surface of the foot may be molded while the footboard is held in position

FIG 93 Short leg cast with walking iron Weight bearing may be permitted in the short leg cast if it is fitted with a walking iron or a rubber heel The walking iron should be placed slightly anterior to the axis of the ankle joint and should extend sufficiently beyond the cast so that on flexion of the knee the front of the cast clears the ground

(Fig 93) This will vary from approximately two to four inches depending upon the degree of equinus in which it is necessary to immobilize the foot

For fractures about the knee joint where the plaster must be extended to include the knee the long leg cast should be employed The bony prominences of the knee and especially the patella should be padded Because of their tendency to break these casts should be reinforced anteriorly or posteriorly by plaster slabs or ropes Hyperextension of the knee should be avoided Slight flexion is not always necessary, though desirable The cast should extend to well above the mid-thigh

THE BODY CAST

The body cast is used to immobilize the dorsal or lumbar spine Below, it extends down to and includes the pelvis, above, it extends a variable distance up on

FIG 94 Body cast Anteriorly and above the cast extends to the level of the angle of Louis Posteriorly, it may be slightly lower and the axillae must be cut out to permit free motion of the arms Below the cast extends to the level of the sacrococcygeal joint posteriorly midway between the crest of the ilium and the tip of the great trochanter laterally and to just above the symphysis pubis anteriorly The groin must be cut out to permit normal flexion of the thigh in sitting

the thoracic wall The bony prominences of the pelvic crest and the ribs must be padded over stockinette To avoid the need for a large window in the cast, a bread-basket made by folding three towels longitudinally is inserted under the stockinette from the symphysis pubis to the sternum This is removed after completion of the cast

The body cast may be applied with the patient either prone or in the standing position In the recumbent position the patient is supported between two tables with the trunk free In the standing position the patient is suspended from an overhead frame by a Sayre halter (Fig 94) Usually four to five layers of plaster are sufficient to assure the strength of the cast When completed, the cast must be trimmed to permit freedom of motion of the arms and legs Above, the axillae must be freed to allow free motion of the arms Below the cast should extend posteriorly to the sacrococcygeal level laterally to a point midway between the iliac crest and the tip of the great trochanter anteriorly to slightly above the symphysis pubis The region of the groin must be cut away sufficiently to allow flexion of the hip without irritation

If the patient is so ill as to preclude movement immobilization can be obtained by the making of plaster of Paris shells Either the back or the front of the patient is well padded and several layers of plaster slabs are placed crisscross upon the exposed region When this has set, the patient is strapped to the plaster shell and is then turned onto the other side A similar procedure is followed on this side so that in effect a bivalved trunk mold has been fashioned For the sake of elegance plaster legs to permit leveling of the mold may be inserted With this double shell

FIG 95 Minerva jacket (*A*) The patient is suspended by an improvised Sayre halter made from a split muslin bandage which is removed after the cast has been completed (*B*) The forehead chin shoulders and trunk are padded

the patient may be easily turned for nursing care without undue pain or disturbance of position If the cast must be applied to immobilize the upper dorsal or the cervical spine the body cast must be extended correspondingly upward

Fixation of the cervical spine is possible by means of a plaster of Paris collar resting on the shoulders or in more extensive lesions by a so-called Minerva jacket The latter may be applied with the patient in the supine sitting or standing position In the standing position head traction is usually obtained by means of a removable makeshift halter made from a muslin bandage The chin shoulders, and occipital region are padded and plaster slabs are laid lengthwise along the area to be immobilized (Fig 95) These are then bound together by circular plaster of Paris bandages Where it is desired to control only flexion and extension well molded chin and occipital slabs are sufficient but where rotation is to be eliminated,

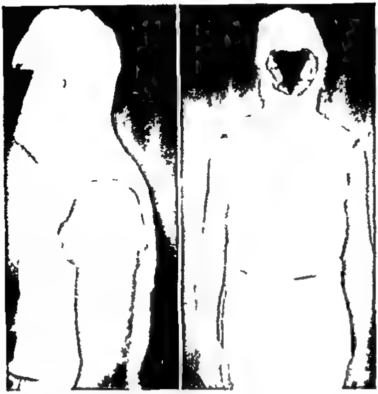


FIG 96 Minerva jacket (*Left*) Side view showing the plaster filet around the forehead the chin platform and freeing of the ears and axillae (*Right*) Front view (See also Fig 119)

a plaster filet around the forehead is necessary The plaster must be cut to permit exposure of the ears as well as motions of the arms and should be bound with adhesive to prevent irritation of the skin (Fig 96)

BODY-EXTREMITY SPICAS

Immobilization of either of the extremities against the trunk is possible only by means of spicas Essentially this is nothing more than a union of the body cylinder with the extremity cylinder The point of union between the two is a point of weakness and must be reinforced by plaster of Paris slabs placed across the line of union

The abduction shoulder spica may be applied with the patient standing, sitting or recumbent Because of the cantilever action of the abducted arm the shoulder spica must extend downward so as to make contact with the padded crest of the ilium To prevent breaking of the spica, the elbow region should be supported by a strut extending from the region of the elbow to the cast as low down as possible (Fig 97) When the arm is adducted the trunk portion of the spica may be shorter and need not impinge on the iliac crest (Fig 98)

The hip spica is usually applied with the patient supine on a fracture table and with the pelvis supported on a pelvic rest Cranially, the spica should extend upward at least to the level of the lower rib cage Failing this the patient invariably complains of pain from pressure of the upper end of the plaster against the ribs

If the patient is so ill as to preclude movement, immobilization can be obtained by the making of plaster of Paris shells Either the back or the front of the patient is well padded and several layers of plaster slabs are placed crisscross upon the exposed region When this has set, the patient is strapped to the plaster shell and is then turned onto the other side A similar procedure is followed on this side so that in effect a bivalved trunk mold has been fashioned For the sake of elegance plaster legs to permit leveling of the mold may be inserted With this double shell

FIG 95 Minerva jacket (*A*) The patient is suspended by an improvised Sayre halter made from a split muslin bandage which is removed after the cast has been completed (*B*) The forehead chin shoulders and trunk are padded

the patient may be easily turned for nursing care without undue pain or disturbance of position If the cast must be applied to immobilize the upper dorsal or the cervical spine the body cast must be extended correspondingly upward

Fixation of the cervical spine is possible by means of a plaster of Paris collar resting on the shoulders or in more extensive lesions by a so-called Minerva jacket The latter may be applied with the patient in the supine, sitting, or standing position In the standing position head traction is usually obtained by means of a removable makeshift halter made from a muslin bandage The chin, shoulders, and occipital region are padded and plaster slabs are laid lengthwise along the area to be immobilized (Fig 95) These are then bound together by circular plaster of Paris bandages Where it is desired to control only flexion and extension, well-molded chin and occipital slabs are sufficient but where rotation is to be eliminated,

FIG. 96. Minerva jacket. (*Left*) Side view showing the plaster filet around the forehead, the chin platform, and freeing of the ears and axillae. (*Right*) Front view. (See also Fig. 119.)

a plaster filet around the forehead is necessary. The plaster must be cut to permit exposure of the ears as well as motions of the arms and should be bound with adhesive to prevent irritation of the skin (Fig. 96).

BODY EXTREMITY SPICAS

Immobilization of either of the extremities against the trunk is possible only by means of spicas. Essentially this is nothing more than a union of the body cylinder with the extremity cylinder. The point of union between the two is a point of weakness and must be reinforced by plaster of Paris slabs placed across the line of union.

The abduction shoulder spica may be applied with the patient standing, sitting, or recumbent. Because of the cantilever action of the abducted arm, the shoulder spica must extend downward so as to make contact with the padded crest of the ilium. To prevent breaking of the spica, the elbow region should be supported by a strut extending from the region of the elbow to the cast as low down as possible (Fig. 97). When the arm is adducted, the trunk portion of the spica may be shorter and need not impinge on the iliac crest (Fig. 98).

The hip spica is usually applied with the patient supine on a fracture table and with the pelvis supported on a pelvic rest. Cranially, the spica should extend upward at least to the level of the lower rib cage. Failing this, the patient invariably complains of pain from pressure of the upper end of the plaster against the ribs

If the patient is so ill as to preclude movement, immobilization can be obtained by the making of plaster of Paris shells Either the back or the front of the patient is well padded and several layers of plaster slabs are placed crisscross upon the exposed region When this has set, the patient is strapped to the plaster shell and is then turned onto the other side A similar procedure is followed on this side so that in effect a bivalved trunk mold has been fashioned For the sake of elegance, plaster legs to permit leveling of the mold may be inserted With this double shell

Fig 95 Minerva jacket (*A*) The patient is suspended by an improvised Sayre halter made from a split muslin bandage which is removed after the cast has been completed (*B*) The forehead chin shoulders and trunk are padded

the patient may be easily turned for nursing care without undue pain or disturbance of position If the cast must be applied to immobilize the upper dorsal or the cervical spine the body cast must be extended correspondingly upward

Fixation of the cervical spine is possible by means of a plaster of Paris collar resting on the shoulders or in more extensive lesions, by a so-called Minerva jacket The latter may be applied with the patient in the supine, sitting, or standing position In the standing position head traction is usually obtained by means of a removable makeshift halter made from a muslin bandage The chin shoulders, and occipital region are padded and plaster slabs are laid lengthwise along the area to be immobilized (Fig 95) These are then bound together by circular plaster of Paris bandages Where it is desired to control only flexion and extension well molded chin and occipital slabs are sufficient but where rotation is to be eliminated

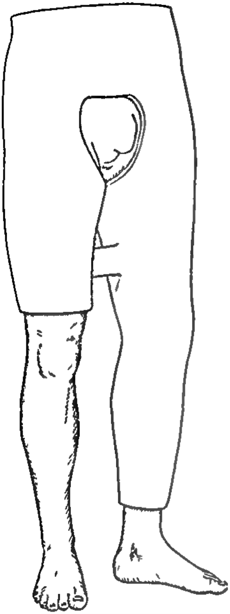


FIG 99 Hip spica When it is desired to immobilize the pelvis and one femur a long plaster must be applied to the involved femur On the opposite side the plaster may be terminated above the knee If only the pelvis is to be immobilized both leg plasters may be terminated above the knee (Short spica)

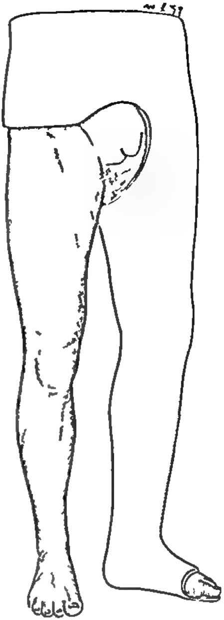


FIG 100 Hip spica When it is desired to control only the femur a single long hip spica may be applied To prevent rotation within the cast the foot should be included in the plaster On its dorsum the foot portion may be cut away to expose the toes but on its plantar surface the plaster should extend beyond the toes to prevent toe drop

FIG 97 Abduction shoulder spica The trunk portion of the shoulder spica should extend down to the iliac crest on the affected side Because of the cantilever action of the abducted arm a supporting strut must be placed from the region of the forearm or elbow to the body of the cast

FIG 98 Adduction shoulder spica When the arm is not abducted the cast need not extend to the crest of the ilium and no supporting strut is necessary

Cutting away of the plaster merely serves to transfer the pressure area distally and necessitates further cutting until the purpose of the cast is completely vitiated Distally the spica may be made short (Fig 99) to just above the knee allowing motion of the knee or long to include the foot (Fig 100) Satisfactory immobilization of either thigh or pelvis is almost impossible by means of a single spica Because of the heavy musculature of the thigh adequate fixation of even a single

CHAPTER 8

Compound Fractures

Compound (open) fractures differ from simple fractures in that they are microbiologically contaminated and present the possibility of frank infection The care of traumatic wounds in general and of compound fractures in particular requires the utmost in surgical skill and judgment Successful management involves a knowledge not only of fractures but also of the special skills developed by the neurosurgeon the vascular surgeon, and the plastic surgeon The ultimate objective is the conversion of a traumatic potentially infected wound into a clean wound free of damaged or devitalized tissue, foreign material, or microbial agents in which the fracture has been properly reduced and immobilized and in which the continuity of the soft tissues has been restored

While the nature of the fracture can be better evaluated from a study of the roentgenogram than from a knowledge of the circumstances under which the fracture was sustained a careful statement of such circumstances may be of considerable value in determining the extent of associated injuries or of the complications that may be expected Specific questioning related to previous cardiovascular, renal or pulmonary diseases diabetes antecedent use of adrenocortical steroids or hypersensitivity to drugs or antibiotics may obviate the subsequent occurrence of otherwise preventable disasters Significant data with respect to the trauma itself should always include exact information relating to the time of the injury, the nature of the terrain in which the injury was sustained whether there was any evidence suggestive of visceral or local neurovascular injury, whether a tourniquet was applied and if applied, for how long a period of time as well as the nature of any first-aid measures that may have been instituted

Maintenance of the voluminous sterile dressing applied to the local wound during first-aid care constitutes the first and foremost principle in avoiding further tissue damage and bacterial contamination of the wound Even for the purpose of making diagnostic x-ray studies splints or dressings should never be removed Interfering clothing should be cut away and not be permitted in any way to hamper adequate medical care It must be the responsibility of the physician in attendance

thigh necessitates the use of a double spica including both thighs Either or both limbs of the spica may be short or long as the occasion demands When the spica has set, the perineal portion is cut away sufficiently to permit exercise of the normal functions The edges of the cast are trimmed, bound with adhesive tape, and may be waterproofed by painting with shellac A crossbar support between the knees or more distally on the cast enhances the strength of the plaster and facilitates handling of the bed patient

anesthetic effects of agents administered by other routes and is often helpful as a hemostatic agent

Following the performance of the field block, the sponge in the wound cavity is carefully teased away and the wound is meticulously inspected for foreign bodies which are removed using finely pointed instruments Profuse bleeding may be encountered during the first phase of debridement It is desirable however not to inflate the tourniquet at this juncture since a more accurate differentiation of healthy from devitalized tissue can be made without its use

Some have advocated that the wound be probed with the finger and irrigated with copious amounts of saline at this time This is probably without potential danger in those wounds that are less than five hours old from the time they have been sustained The so-called golden period corresponds with the latent period in the bacterial growth curve and represents that time interval in which wounds may be considered as only contaminated Afterward during the interval representing the logarithmic phase of bacterial reproduction and invasion concomitant with which the wound becomes frankly infected it is probably safer to defer irrigations until after the completion of adequate thorough yet conservative debridement Irrigations prior to this time make the differentiation of devitalized from normal tissues more difficult and have the additional disadvantage of frequently obscuring small foreign bodies

After grossly discernible foreign bodies have been thoroughly removed a sterile dry gauze dressing is placed in the wound cavity and the skin surrounding the wound margins is excised Excision of the skin should generally be limited to a margin approximately 0 5 cm from the wound margin though this will obviously differ with patients and with different wounds in varying locations It is in general however, desirable to aim at skin excisions not exceeding this width

With the gauze sponge in the wound cavity and using finely pointed instruments the skin incisions should then be developed into but not through the subcutaneous fatty tissues Bleeding is usually not severe during this maneuver and as few bleeding vessels as possible should be clamped and ligated As the tissue is cleanly incised a sterile dry fine meshed gauze sponge is placed about its margin so that following the skin excision the wound will be packed off from the healthy cleanly incised tissue by a wall of dry fine meshed gauze

After the skin margins have been completely excised down into the subcutaneous fatty layer the clean skin flaps should be widely undermined using clean instruments until the subcutaneous fat joins the superficial layer of deep fascia

Following this hand traction should be gently exerted on the gauze covering the tissues of the contaminated wound and by sharp dissection the deeper layers of the wound are cleanly excised Considerable bleeding may be encountered during this phase and it may be found desirable to inflate the tourniquet and thus to obtain a dry operative field before continuing the dissection

When under tourniquet control extra care must be taken carefully to distinguish normal from devitalized tissue and not to sacrifice functional vital tissues The dissection is then carried down until the bone and periosteum about the frac-

to assure that the patient is moved as infrequently as is at all possible. When the patient must be moved, he should be moved not only under the supervision of the physician in attendance, but actually by him However well trained and however experienced ancillary personnel may be, they almost never fully appreciate the multiple problems and possibly preventable complications that may arise from subjecting the wound to additional, unnecessary trauma

Following the completion of the necessary x ray studies precise assay of the type and extent of the local wound should be undertaken, but only in the operating room Under no circumstances should an open fracture be debrided anywhere but in the operating room Ideal treatment dictates that as soon as a patient with an open fracture is admitted to the emergency ward, the operating room staff be notified and arrangements be made for immediate transfer of the patient to the operating theater With the exception of life threatening problems there is no surgical indication of a more urgent nature than that of an open fracture Time is of the essence and a delay of several hours may serve to convert a contaminated into a frankly infected wound All considerations of alignment of the fracture become secondary to those associated with debridement of the wound

Wound Debridement

Debridement of open fractures must be performed under aseptic conditions in every way identical with those of any other major surgical procedure In most cases, it is preferable that the patient receive a general inhalational anesthetic though in certain circumstances nerve plexus blocks or intravenous administration of analgesics muscle relaxants, and ganglionic blocking agents may also be suitable In all circumstances the operator must have adequate assistance instruments good light, and ready access to the wound unhampered by faulty position of the limb or of the patient

The surgeon should scrub in accordance with strict aseptic technic and wear cap, mask, gown and gloves as do all others of the operating personnel External splints and the outer layers of the voluminous sterile pressure dressing are first removed by an assitant and a pneumatic tourniquet is placed but not inflated about the proximal portion of the involved extremity A scrubbed and gloved assistant then removes the innermost layers of the compressive dressing using instruments that are promptly discarded as soon as the wound is exposed

After the superficial aspects of the wound have been examined and before it has been in any way disturbed a dry gauze sponge is placed in the wound cavity so that the entire superficial extent of the wound is packed off from the surrounding skin surface without overhanging gauze margins Grease or other oils should be removed from the surface by acetone benzene ether or other available organic solvent before the skin is shaved The skin is then widely shaved about all sides of the wound and the entire extremity is prepared and draped as for any other major surgical procedure

After the field has been cleansed and draped and the skin surface is dry a local anesthetic field block may be performed Local anesthesia serves to enhance the

the tendency toward window edema. If at the end of four or five days there is no evidence of gross infection the wound may be closed by interrupted sutures after the margins of the fat layer are trimmed. A compression dressing should be placed over the wound site and the window in the cast may then be closed. Skin sutures need not be removed if there is any danger of disturbing the processes of healing in the underlying fracture. The wound itself should not be inspected until satisfactory healing of the fracture has occurred unless there is evidence suggestive of infection at the fracture site. Where there is frank infection treatment of the fracture becomes of secondary importance to the treatment of the infection.

INFECTED WOUNDS

Statistically, wounds that have been debrided adequately within six to eight hours of the time they have been sustained are less likely to become subsequently infected than those initially treated at later times. Adequate debridement during this interval is, however, not a guarantee that infection will not supervene and conversely debridement carried out after this time may be perfectly satisfactory in obviating infection. Clearly, the important factors are those relating to the ability of bacteria to become established in a wound and to grow and invade the tissues of the wound once they have become established. Specifically, these relate to (1) the relative extent of the gross contamination and tissue destruction of the wound itself, (2) the geography and characteristics of the locale in which the wound was sustained, (3) the nature and concentration of the inoculum of bacteria, (4) the time interval between wounding and the institution of therapy, (5) the immunity of the host, and (6) the type of initial treatment of the wound.

Once the basal layer of epidermis in any particular region has been penetrated a wound is established that, by definition, is open to the external environment and hence is contaminated.

Wound size is of importance in the contamination of previously undisturbed tissues primarily insofar as it relates to the size of the microbial inoculum and to the type of medium into which the inoculum is introduced. Bacteria are more likely to become established in the larger wounds since the medium into which they are inoculated is particularly well adapted to their growth. The large wounds are more frequently associated with massive tissue destruction and devitalization than are their smaller counterparts and are more likely to contain greater quantities of more heavily contaminated foreign material. In general, there is a direct relationship between the volume and concentration of the contaminating inoculum and the volume of the wound.

In wounds of comparable size those produced by crushing injuries tend to be more suitable for bacterial growth than are those produced by penetrating injuries since the amount of tissue destruction is in general greater in the former than in the latter. Likewise penetrating injuries such as bullet wounds tend to be associated with more tissue destruction and more microbial contamination than are simple cleanly incised wounds.

The nature of the microbial contaminants of any open wound is dependent

ture site are clearly identified for a distance of several centimeters on either side of the line of fracture All tissue of the local wound, including denuded and de vitalized periosteum, should, after proper debridement, be capable of being lifted en masse from the fracture site, leaving a cleanly incised margin of healthy tissues

When this has been completed, attention may be directed to the fracture itself Foreign bodies and small, loose bone spicules may be removed and discarded Larger bone segments should be carefully preserved their surfaces cleanly shaved (using a sharp scalpel or osteotome), and washed with water and saline for possible subsequent replacement in the fracture site

Only after this stage has been completed is it safe to begin with irrigation of the wound Small amounts of sterile water may be used first to lyse any blood clots Copious amounts of warm isotonic saline are then irrigated into the wound both before and after the tourniquet has been released to remove mechanically any minute freely lying foreign bodies and freely floating bacterial colonies

Bleeding from small vessels may be controlled by temporarily packing the wound with hot saline pads but larger vessels should be secured by means of the finest suture material compatible with the size of the vessel

Within the first six hours after injury, before frank infection has occurred, the fracture may be reduced by using bone holding hooks or clamps and as many of the previously debrided bone fragments as are available may be replaced in the fracture site Postreduction alignment may be obtained by the use of traction or transcortical fixation devices Where there is actual loss of bone substance the length of the limb may be maintained by transfixion wires or nails through the proximal and distal fragments and anchored in the windowed plaster of Paris cast that is later applied Despite the fact that intramedullary fixation and even bone grafting have been used in the immobilization of these types of fractures it is probably safer to avoid this type of fixation even in the early period after the injury

When the fracture has been adequately reduced and rigidly fixed the wound is again irrigated, using small amounts of water followed by copious amounts of saline The periosteum where available is then closed using interrupted absorb able sutures and the fascial layers are loosely approximated in the same manner The sutures in all layers should be placed no closer than 2 cm apart to permit of fluid passage between the layers and if infection subsequently supervenes of drainage of the wound

Some have advocated the primary closure of the skin wound in compound fractures This is justifiable only if definitive treatment can be instituted shortly after the injury Where there is any question as to the likelihood of later infection it is probably safest to leave the superficial tissues of the wound unclosed for a period of about five days This is the period within which infection may develop particularly that resulting from anaerobic bacteria and the patient s interests are not in any manner jeopardized by leaving the wound packed loosely open

A compressive dressing is applied and the limb is immobilized either in traction or in a windowed plaster of Paris cast exposing the entire area of the wound The window in the cast should allow sufficient margin around the wound to minimize

The volume of the bacterial inoculum is of importance since the number of communicable mutants or variants capable of producing a response in the host is greater when the inoculum is large than when it is smaller Similarly the more concentrated the inoculum of virulent organisms the greater is the likelihood of infectability Infectability is modified in part by the dominant phase of the growth cycle of the inoculum Organisms in the lag (latent) phase of the growth cycle in which new bacterial protoplasm is being synthesized but in which cell multiplication is not appreciable and those in the logarithmic phase in which cell multiplication occurs almost simultaneously with protoplasmic synthesis are particularly prone ultimately to establish infections under otherwise suitable conditions Those in the resting stage the stationary phase in which cell division and cell death occur at about equal rates and those in the decline phase in which cell death occurs at a progressively greater rate than does cell division are less likely to become established in a new environment than their more youthful active homologues On the other hand once they become established in a wound such organisms are less likely to be affected by untoward environmental factors such as disinfectants and chemotherapeutic agents

As soon as pathogenic bacteria have been implanted in a wound a multitude of cellular and humoral mechanisms are called upon by the host in an attempt to combat the threat of infection These constitute the host s immunity Therapeutic measures that can be undertaken to enhance this are limited On the other hand much can be done to prevent the growth and invasion of bacteria by proper surgical intervention This involves primarily incision drainage and debridement

As a general rule, bacterial reproduction does not become apparent until six to eight hours after an infective inoculum has been implanted into a suitable wound This so-called golden period thus represents the average time interval within which most wound infections can be combated by adequate debridement It is in this interval that the host s defenses are being mobilized, while the inoculum generally though not necessarily is in the lag phase of its growth cycle

Vigorous and when indicated repeated debridements and liberal incisions are the mainstays of the surgical approach to established infections Small incisions and conservative debridement in grossly infected wounds always lead to inadequate drainage and ultimately to greater loss of time and greater morbidity than does aggressive initial surgery Incisions should always be sufficiently large to permit of total excision en masse of the infected region without the necessity for probing its depths and thereby introducing infected material into healthy tissue The same care must attend the removal of all retained foreign bodies excision of necrotic and devitalized tissue sinus tracts fistulae and the fibrotic walls of ab cess cavities as for primary debridement of a noninfected wound To prevent wound seeding with infected material instruments, gloves and gowns should be changed in precisely the same manner as is the custom for cancer operations of whatever magnitude Enzymatic debridement using trypsin streptococcal proteinase or streptodornase-streptokinase preparations are a valuable supplement to surgical intervention where anatomical conditions forbid thorough debridement but in no instance is enzymatic therapy or antibiotic therapy alone indicated Wher-

upon the anatomical region involved as well as the terrain in which the wound was sustained Industrial or war wounds may be contaminated with quite different flora from those sustained elsewhere Wounds received in the field often have clostridia or Gram-negative enteric bacilli, while wounds sustained in the home or at sea are more apt to be contaminated by bacteria of the more common pyogenic varieties Milk bottle injuries are frequently contaminated with *Streptococcus lactis* or *Lactobacillus*

Wounds about the proximal portions of the lower extremities are more likely to have *E coli* than are those of the distal portions, owing to their proximity to the anus Wounds in the proximal portions of the upper extremities tend to have streptococci owing to their relationship to the upper respiratory tract Wounds of the distal portions of the extremities are more likely to be contaminated by streptococci and staphylococci

Whether or not bacteria can become established and grow in a wound depends upon (1) the dose and virulence of the inoculated organisms and (2) the host's response to the inoculum The biologic contest between the host and the implanted organisms determines whether or not the wound remains solely contaminated, becomes septically broken down, or is invasively infected Classically, wound infections are either localized, in which there is suppuration of locally damaged tissues and hematomas unassociated with any constitutional symptoms, or invasive, in which the organisms invade the healthy tissues surrounding the suppurative focus The latter are clinically characterized by cellulitis, lymphangitis, and not infrequently the systemic manifestations of chills, fever, tachycardia, malaise weakness, and prostration considered typical of toxicity

When the organisms establish themselves within the host tissues without evoking a response or after initially producing a response, persist without a subsequent reaction, a symbiotic relationship is established within the host such that the implanted organisms may be considered as being benign saprophytes On the other hand, many bacteria elicit a more or less characteristic response, a disease process, when implanted in host tissues These pathogenic organisms in contradistinction to the saprophytes produce variably severe host reactions and are accordingly, variably virulent for the particular individual An intermediate condition, the so-called carrier state may exist in individuals either recovered from infection or never clinically ill Fully pathogenic bacteria may exist harmlessly as native organisms on the skin and mucous membranes When introduced into other areas, not their normal habitat, these same organisms are capable of producing serious wound infections The mere bacteriological demonstration of the existence of organisms in the wound is however not evidence of their pathogenicity Wound infection is a purely clinical phenomenon

The causative organisms in most surgical infections tend to be aerobic and either Gram positive cocci or Gram negative bacilli less frequently, anaerobic or microaerophilic Gram positive cocci and bacilli In order of their usual frequency, surgical infections arise in consequence of the establishment and multiplication within host tissues of (1) staphylococci (2) streptococci, (3) enteric bacilli and enterococci, and (4) *clostridia and microaerophilic streptococci*

addition, may sensitize the patient to the antibiotic agent used. This is especially true of staphylococcal infections.

When no indication whatever concerning the nature of the causative organism is available, it is preferable to employ symptomatic therapy until such time as cultures and sensitivities can be determined. The important concept in antibiotic therapy is the rapid determination of the proper antibiotic agent and its administration in high doses so that the tissues are constantly bathed by a high concentration of the agent.

Theoretically, chemotherapeutic agents may be either synergistic or antagonistic when used in combination. When combined therapy is used, it is important to obtain sensitivity tests, preferably using the more reliable tube sensitivities than the more frequently fallible disc methods. Generally considered, the antibacterial agents may be divided into two groups. The first, comprising penicillin, streptomycin, bacitracin, neomycin, polymixin, and erythromycin, are bactericidal in high concentrations and bacteriostatic in lower concentrations. They tend to be synergistic when used in combination and are almost never antagonistic. The second group, comprising the sulfonamides, the tetracyclines, and chloramphenicol, are usually bacteriostatic irrespective of concentration and are not synergistic but only additive in their combined effects. If an organism is sensitive to agents in either of the two groups, it is preferable to use only agents in one of the groups since the combination may lead to an increased over-all resistance on the part of the organisms. If, on the other hand, the organism is only slightly sensitive to agents in both groups, the use of a combination of agents in both groups may enhance the over-all sensitivity of the organism to the combined therapy.

Vascular Injuries

Vascular injuries are not infrequently associated with severe fractures and may vary, even in simple fractures, from transitory segmental spasm to complete anatomical severance of the major vessels. Injuries to neighboring veins are more frequent than to the corresponding arteries, but in general are less likely to affect adversely either the life or limb of the patient. Indeed, venous injury appears to be present in virtually all fractures. Few of these, however, either require or are amenable to surgical correction. On the other hand, arterial injuries, although less common and more serious to the patient, are, fortunately, more frequently remediable by established surgical technics.

Complete interruption of the arterial supply to an extremity is more likely to occur in comminuted, open fractures with large losses of substance. Where there is no massive loss of substance, arterial injuries tend to result from perforations, incomplete lacerations, or, most frequently, vasospastic phenomena. The important therapeutic consideration is the rapid determination of the presence and, if possible, the etiology of total ischemia.

Clinically, frank ischemia is classically manifested by pain, pallor, absence of pulse, paralysis, and paraesthesias distal to the point of arterial obstruction. Pain may mask all other symptoms and may at first be indistinguishable from paresthetic

ever indicated at all, they are indicated solely as adjuvants to proper surgical treatment

Every effort should be made to convert the infected, open wound to a noninfected closed wound at the earliest possible moment using free skin grafts, pedicle grafts, and other plastic surgical procedures Frequently changed wet dressings and irrigations of hydrogen peroxide and saline tend to minimize bacterial contamination and embolization postoperatively Elevation of the involved part promotes venous drainage and discourages both edema formation and thrombosis Immobilization either by the use of compressive dressings or, preferably, by dressings within bivalved casts obliterates dead space, discourages oozing and hematoma formation and favors optimal healing

The treatment of established infection in bone may be by repeated debridements, as indicated, or by means of the Orr method The essence of this last method of therapy consists of thorough debridement of the bone wound followed by packing with petrolatum gauze to avoid the formation of dead space in which pus may pool To maintain or restore the length of the limb transcortical fixation pins are passed through the proximal and distal fragments of the bone and are then incorporated in the plaster of Paris cast used to immobilize the fracture Unless there is clinical evidence of retention of pus the wound is left undisturbed in the cast for a period of five to six weeks before the cast and dressing are changed

Equally satisfactory results have been obtained by debridement and delayed closure after all signs of infection have subsided In chronic infection of bone, it has been found possible to close the wound primarily after complete debridement well into healthy bone tissue and installation of antibiotic solutions into the wound Systemic antibiotics are administered at the same time

Within the past two decades a profound change has taken place in the clinical manifestations and treatment of most infections Surgical infections have been particularly modified by the widespread and often indiscriminate use of chemotherapeutic and antibiotic preparations Infections by organisms such as the beta hemolytic streptococcus have become less frequent and organisms formerly considered as semisaprophytes or minor pathogens have become serious therapeutic problems The emergence of resistant strains of organisms especially staphylococci the development of superinfections, the overgrowth of fungi and the increase in hypersensitivity phenomena during antibacterial therapy have become problems as perplexing and occasionally as fatal in outcome as had previously been the case

Antibiotics are the greatest value when used systemically Local applications of antibiotic preparations have definite though limited usefulness They have definitely minimized the spread of infection but have not been shown materially to decrease either the incidence or the severity of localized foci of infection Proper antibiotic therapy is always dependent upon the results of sensitivity examinations of both aerobic and anaerobic cultures of the organisms recovered from the wound Antibiotic therapy employed without such prior investigations may have no untoward effect on the organisms or may on the contrary promote the development of otherwise resistant strains permit overgrowth of semisaprophytes and fungi, alter the host s natural and acquired resistance to the infecting organisms and in

When a diagnosis of acute posttraumatic arterial occlusion with an inadequate collateral circulation that does not respond to sympathetic ganglion blockade has been established it must be assumed that there is a mechanical obstruction to arterial blood flow and the possibility of relief by surgery must be contemplated

At the time of operation it is imperative that adequate visualization and complete control of both the proximal and distal portions of the injured vessel be obtained This is accomplished by placing the incision directly along the anatomical course of the vessel and directly over the site of the suspected lesion The dissection is carried down through the vascular sheath that surrounds the vessel and all its collaterals These are identified freed from the surrounding tissues and meticulously preserved

Localized segmental spasm or thrombosis is usually apparent on exposing the involved vessel Warm saline packs directly applied to the vessel probably constitute the best means of therapy for spastic vessels Embolectomy or thromboendarterectomy as indicated is a useful procedure for vessels proximal to the knee and elbow joints but more peripherally both are contraindicated owing to the probability of postoperative thrombosis of the vessel lumen

Partial lacerations and perforations of arteries should be directly sutured after minimally trimming the edges of the defect provided that the vessel defects occur proximal to the knee or elbow joints Distally, suture of the wall without trimming should be undertaken This is performed merely to prevent further bleeding and in the hope that a collateral circulation may develop before complete thrombotic occlusion of the lumen ensues Complete hemostasis proximally is obtained by placing rubber-shod bulldog clamps across the vessel to obstruct the lumen A small segment of vessel at the site of laceration or perforation may be trimmed if indicated so as to permit accurate intima to intima approximation Excessive debridement however inevitably results in secondary thrombosis at the anastomatic site (Fig 101)

Closure is effected by placing a single through and through No 6–0 waxed atraumatic silk suture at either apex of the defect and leaving the tied ends long for traction purposes Interrupted everting mattress sutures or a continuous through-and through silk suture is placed across the arteriotomy wound to achieve intima-to intima approximation of the margins The sutures are placed so that each includes only about 2 to 3 mm of arterial wall on either margin and are drawn snugly but not tightly together Before closure is completed it is advisable to instill approximately 20 ml of a 0 01 per cent heparin solution into the arterial lumen both proximal and distal to the occluding clamps * After the anastomosis has been completed the distal clamp is removed first The proximal clamp is then opened but not lifted away from the vessel There will be some slight bleeding through the needle hole sites and between the sutures immediately upon release of the clamp but this

* Some surgeons prefer to administer heparin intravenously during the course of the operative procedure (20–30 mgms I V as an initial dose and thereafter 10 mgms every hour during the operation) and to discontinue heparin immediately postoperatively When this or a similar regimen is employed Intraarterial anticoagulants need not be employed

symptoms of burning, itching, cramps, tenderness, tingling or numbness. Pallor is not always present and may be supplanted, if there is concomitant subcutaneous bleeding and stasis, by a brawny, dusky rubor and edema. Acute pain with pallor and pulselessness, however, is virtually pathognomonic.

When peripheral pulses are absent in a fractured extremity, it is most important to differentiate between pre-existing vascular disease and possible acute arterial interruption. In some instances an adequate history is helpful, but in others it may be necessary to rely upon objective test procedures.

Clinical examination with particular reference to the status of the pulses, oscillometry in the thighs and calves, and the presence or absence of rubor on dependency and blanching on elevation in both the affected and nonaffected limbs probably provide the most informative data as regards the peripheral circulation. Objective skin temperature determinations in cold and warm atmospheres and the comparative response of the affected and uninvolved extremities to the intradermal injection of 0.1 ml. of 1:1,000 histamine may likewise be of value. More elaborate technics, such as direct or percutaneous arteriography or venous occlusion plethysmography, are probably contraindicated when acute, complete anatomical interruption of a major artery is suspected, but they may occasionally be of some value in differentiating between acute segmental spasm and partial interruption from antecedent obliterative vascular disease.

Sympathetic ganglion blockade using local anesthetic agents is a most expeditious method of differentiating acute spasm from other conditions. In the upper extremity, this is accomplished by injection of the stellate ganglion and in the lower extremity by injections of the paravertebral sympathetic ganglia. In the event that the occlusion is entirely of a vasospastic nature, interruption of the sympathetic vasoconstrictor fibers will relieve the condition. The anesthesia may be continued as a therapeutic measure either by repeated injections or by continuous perfusion through a small indwelling catheter. Even if there is no return of pulsation, ganglionic blockade may suffice to establish the efficiency of the collateral circulation and thus prevent ischemia of the affected limb.

The most useful and reliable test for determining the adequacy of the collateral circulation, both preoperatively and intraoperatively, is that designed by Matas. With the involved limb elevated above the level of the right atrium, the blood in the extremity is milked out by the use of an Esmarch or other elastic bandage. The extremity is then permitted to remain ischemic in the elevated position for a period of approximately five minutes. After about three minutes in this position, the artery just proximal to the suspected site of occlusion is compressed digitally so that there is no peripheral blood flow. About two minutes thereafter, at the end of the five-minute period of Esmarch bandage compression, the limb is lowered to the horizontal position *while* compression of the artery is continued. An adequate collateral circulation is manifested by flushing of the extremity within a period of about two minutes after release of the bandage. Extremities that remain pallid or otherwise unchanged in color may be considered to have inadequate collateral arterial channels.

When a diagnosis of acute posttraumatic arterial occlusion with an inadequate collateral circulation that does not respond to sympathetic ganglion blockade has been established it must be assumed that there is a mechanical obstruction to arterial blood flow and the possibility of relief by surgery must be contemplated

At the time of operation it is imperative that adequate visualization and complete control of both the proximal and distal portions of the injured vessel be obtained This is accomplished by placing the incision directly along the anatomical course of the vessel and directly over the site of the suspected lesion The dissection is carried down through the vascular sheath that surrounds the vessel and all its collaterals These are identified freed from the surrounding tissues and meticulously preserved

Localized segmental spasm or thrombosis is usually apparent on exposing the involved vessel Warm saline packs directly applied to the vessel probably constitute the best means of therapy for spastic vessels Embolectomy or thromboendarterectomy, as indicated is a useful procedure for vessels proximal to the knee and elbow joints but more peripherally both are contraindicated owing to the probability of postoperative thrombosis of the vessel lumen

Partial lacerations and perforations of arteries should be directly sutured after minimally trimming the edges of the defect provided that the vessel defects occur proximal to the knee or elbow joints Distally suture of the wall without trimming should be undertaken This is performed merely to prevent further bleeding and in the hope that a collateral circulation may develop before complete thrombotic occlusion of the lumen ensues Complete hemostasis proximally is obtained by placing rubber-shod bulldog clamps across the vessel to obstruct the lumen A small segment of vessel at the site of laceration or perforation may be trimmed if indicated so as to permit accurate intima to intima approximation Excessive debridement however inevitably results in secondary thrombosis at the anastomatic site (Fig 101)

Closure is effected by placing a single through and through No 6–0 waxed atraumatic silk suture at either apex of the defect and leaving the tied ends long for traction purposes Interrupted everting mattress sutures or a continuous through-and through silk suture is placed across the arteriotomy wound to achieve intima-to intima approximation of the margins The sutures are placed so that each includes only about 2 to 3 mm of arterial wall on either margin and are drawn snugly but not tightly together Before closure is completed it is advisable to instill approximately 20 ml of a 0 01 per cent heparin solution into the arterial lumen both proximal and distal to the occluding clamps * After the anastomosis has been completed the distal clamp is removed first The proximal clamp is then opened but not lifted away from the vessel There will be some slight bleeding through the needle hole sites and between the sutures immediately upon release of the clamp but this

* Some surgeons prefer to administer heparin *intravenously* during the course of the operative procedure (20–30 mgms I V as an initial dose and thereafter 10 mgms every hour during the operation) and *to discontinue* heparin immediately postoperatively When this or a similar regimen is employed Intraarterial anticoagulants *need not* be employed

usually subsides promptly if the anastomosis is adequate If the anastomosis is adequate, it is desirable that some muscle or other soft tissue be placed in proximity to the line of suture, though this is not essential

Arteries that have been completely severed or have been severely traumatized can be treated either by ligation, resection, and graft anastomosis or by the placing of a bypass graft Grafting procedures are better left to those with special training than to the occasional vascular surgeon Occasionally, however an arterial graft must be placed by the fracture surgeon Wherever possible, direct anastomosis using

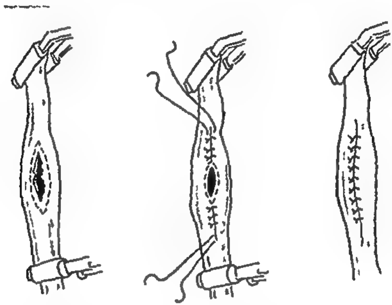


FIG 101 Suture of perforated artery In the larger vessels debridement may be performed Traction sutures are placed at the upper and lower angles of the wound and the defect may be closed using either interrupted mattress sutures or a continuous over and over stitch The distal clamp is removed first following closure of the arteriotomy wound

the Linton technic is preferable to the insertion of free grafts (Fig 102) Where this is not possible free grafts using either autogenous or homologous vessels may be employed Where a vein is used, it must be reversed so that the venous valves do not impede flow and hence promote thrombosis

Only in the gravest of emergencies should large injured vessels be ligated When ligatures must be placed however they should be placed perpendicular rather than oblique to the long axis of the vessel and as close to the mainstem as possible This obviates the creation of a blind sac immediately proximal to the point of ligature and lessens the tendency for the sutures to be displaced by arterial pulsations Through-and through transfixing sutures should always be used in addition to the ligature in the ligation of all the larger vessels

Postoperatively or in cases where operative repair of an injured vessel is contra indicated, the limb must be carefully protected from mechanical trauma or the pos-

sibility of infection. This may, of course, preclude the use of an immobilizing plaster cast in the treatment of a comminuted fracture, which is, after all, secondary to the preservation of the circulation of the limb. No clothing should be placed on the involved extremity, which should be additionally protected by an adequate cradling device. It is desirable to use a pneumatic mattress with alternately inflating ribs to prevent additional trauma resulting from dependency. If this is not available, however, either blankets or other nonirritating bed clothing may be employed and the position of the extremity should be changed at periodic intervals. The extremity

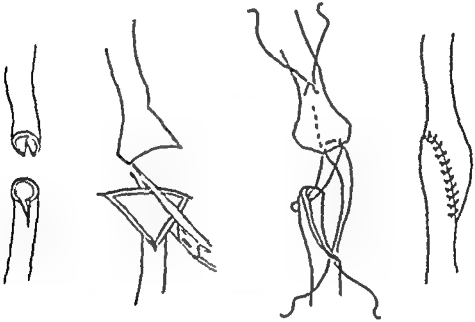


FIG. 102. Linton technic of arterial anastomosis. A longitudinal incision is made through the anterior wall of one of the segments of the severed artery and through the posterior wall of the adjacent segment. The cut ends of each segment are then trimmed so that the resulting anastomosis permits end-to-end approximation of the segments using a side-to-side technic. (Modified from Linton, R. R.: Practical considerations in the surgery of blood vessel grafts. *Surgery* 38:817, 1955.)

should be kept in a slightly dependent position, but venous obstruction and edema formation should not be permitted to occur as a consequence of dependency. In lower extremity occlusions, an oscillating bed set so that oscillations are of a short arc may be desirable. Lambs' wool should be inserted in all intertriginal regions, particularly between the toes, to prevent maceration of poorly nourished tissues. Above all else, the extremity should be maintained at room temperature. Cooling serves to diminish blood flow and warming both increases the metabolic requirements of the malnourished tissues and encourages stasis.

NERVE INJURIES

In principle, the management of acute peripheral nerve injuries is identical with that of other soft tissues, being governed in great measure by the length of time

since the injury and the nature and extent of bacterial contamination and tissue destruction There is, however, one specific exception, the possibility or even presence of infection in a wound with an acute peripheral nerve injury is not a contraindication to definitive suture *provided* that the wound has been otherwise thoroughly debrided

Recognition of the presence of a neural injury, especially when symptomatic complaints referable to the nerve itself may be masked by symptoms arising from the fractured bone, is frequently overlooked in the definitive management of such fractures Despite clear differences in their anatomical position and appearance the distinction between nerves and other structures, such as tendons may occasionally be most difficult in those fracture wounds that require debridement

Clinical recognition of injury to nerves is afforded by determination of the loss or absence of their specific vasomotor, reflex, motor, or sensory functions Color and temperature of the unaffected as compared with the involved limb and the presence or absence of arterial pulsations and sweating in either limb should always be noted at the time that the patient is initially seen and at each subsequent examination Loss of the appreciation of pin prick stimulation over the distal phalanges of the hand loss of opponens motion in the thumb, and loss of the ability to extend the wrist present unequivocal evidence of neural dysfunction in the upper extremity In the lower limbs inability to plantar flex or dorsiflex the foot or loss of sensation over the medial and lateral surfaces of the foot provide similar evidence for the presence of an injury, anatomical or physiological to specific peripheral nerves These signs must be carefully sought for in any fracture, even in those in which there is little clinical evidence of their existence A single examination for a peripheral nerve injury is about as informative as no examination at all Depressed axonal conduction may vary considerably with elapsed time and at one time there may be little or no evidence of nerve dysfunction, while at some later time, without intervening additional injury, signs of nerve dysfunction may be obvious

It is of particular importance to remember that despite clear cut clinical evidence pointing to nerve interruption no such lesion may be demonstrated at the time of operation Preoperatively there is no known way to make the differentiation between anatomical severance and functional nerve disturbance owing to contusion or traction

Where at open operation nerves have been demonstrated to be anatomically frayed or severed several therapeutic approaches are available In military medicine delayed suture of peripheral nerve injuries is the more usual method of management Following adequate debridement closure of the soft parts without tension over the noncoapted nerve ends with delayed closure of superficial tissues and the skin is the recommended practice The severed nerve ends are covered with viable muscle to prevent further nerve damage that may arise from dressings placed in the wound cavity Definitive nerve suture is ideally performed about three to four weeks following injury about two weeks after good healing has been obtained Optimal functional recovery has been found to be obtainable at almost any time up to three months after injury but after six months despite even technically perfect nerve suture the results of suture are almost universally disappointing

In civil injuries, on the other hand, both primary and delayed nerve suture have been advocated. Experience with the delayed suture method in war situations has been so gratifying that some surgeons, especially those who only occasionally deal with nerve injuries, have preferred to adopt this method. Others, however, have argued that *primary suture is the preferable method*.

Primary suture is clearly applicable in those favorable cases in which the patient when first seen is not in shock or otherwise generally incapacitated and is seen *within three or four hours of injury with a relatively uncomplicated wound neither* grossly contaminated with potentially infective material nor containing gross amounts of devitalized tissue. Even in unfavorable cases, however, in which the converse situation exists, experience has indicated that primary nerve suture is *still not contraindicated, provided that adequate debridement is carefully performed* along with the primary anastomosis. In the most unfavorable of cases, which in war conditions would clearly be treated by delayed suture, where there is gross pus present in the wound and in which it is feared that any anastomosis would break down, it may be preferable to coapt the severed epineuria of the nerve ends by loosely tied stainless steel sutures.

Dogmatic dicta, obviously, are difficult to establish. As a general rule, however, it is *probably safest to limit primary nerve suture following traumatic division to* those instances in which the cut nerve is not severely contused and to employ delayed suture in all other neural injuries.

Where actual repair is to be undertaken, a tourniquet will usually be required, even for delayed repair, and it is best to place this on the proximal portion of the involved extremity before any preoperative maneuvers are started. Since it may be *desirable to examine the peripheral structures after the operative procedure has* begun, preparation of the entire extremity distal to the tourniquet should be undertaken. To prevent excessive venous oozing, the limb should be elevated, then milked of its blood by means of an Esmarch or other elastic bandage before the tourniquet is inflated.

The skin incision should be placed directly over the longitudinal course of the nerve except at flexion creases, where a Z-shaped, laterally placed incision should be employed. The nerve should then be identified and immobilized over a distance of about 1 to 2 cm. on either side of the line of severance. A single No. 4–0 suture with a swedged-on needle is then placed through the epineurium of each segment of nerve about 2 cm. from the line of eventual anastomosis to serve as guide sutures. These should be so placed as to align the funiculi in the two segments of the nerve. A longitudinal vessel usually seen on the surface of the nerve affords an excellent guide for such anatomical realignment.

A small ribbon retractor covered with a fine-meshed moist gauze is then placed beneath the nerve at the site of the contemplated anastomosis. The nerve ends are freed and damaged portions of the ends cleanly resected using a sharp knife or razor blade held perpendicular to the long axis of the nerve. *Approximately 1 mm.* serial sections are then made partially through the nerve so that a small bridge of nerve tissue remains intact for traction purposes. The tissue slices are cut back sequentially until the normal anatomical appearance of the neural funiculi is recog-

since the injury and the nature and extent of bacterial contamination and tissue destruction There is, however, one specific exception, the possibility or even presence of infection in a wound with an acute peripheral nerve injury is not a contraindication to definitive suture *provided* that the wound has been otherwise thoroughly debrided

Recognition of the presence of a neural injury, especially when symptomatic complaints referable to the nerve itself may be masked by symptoms arising from the fractured bone, is frequently overlooked in the definitive management of such fractures Despite clear differences in their anatomical position and appearance, the distinction between nerves and other structures, such as tendons may occasionally be most difficult in those fracture wounds that require debridement

Clinical recognition of injury to nerves is afforded by determination of the loss or absence of their specific vasomotor, reflex, motor, or sensory functions Color and temperature of the unaffected as compared with the involved limb and the presence or absence of arterial pulsations and sweating in either limb should always be noted at the time that the patient is initially seen and at each subsequent examination Loss of the appreciation of pin prick stimulation over the distal phalanges of the hand, loss of opponens motion in the thumb and loss of the ability to extend the wrist present unequivocal evidence of neural dysfunction in the upper extremity In the lower limbs, inability to plantar flex or dorsiflex the foot or loss of sensation over the medial and lateral surfaces of the foot provide similar evidence for the presence of an injury, anatomical or physiological to specific peripheral nerves These signs must be carefully sought for in any fracture even in those in which there is little clinical evidence of their existence A single examination for a peripheral nerve injury is about as informative as no examination at all Depressed axonal conduction may vary considerably with elapsed time and at one time there may be little or no evidence of nerve dysfunction while at some later time without intervening additional injury signs of nerve dysfunction may be obvious

It is of particular importance to remember that despite clear cut clinical evidence pointing to nerve interruption no such lesion may be demonstrated at the time of operation Preoperatively there is no known way to make the differentiation between anatomical severance and functional nerve disturbance owing to contusion or traction

Where at open operation nerves have been demonstrated to be anatomically frayed or severed several therapeutic approaches are available In military medicine delayed suture of peripheral nerve injuries is the more usual method of management Following adequate debridement closure of the soft parts without tension over the noncoapted nerve ends with delayed closure of superficial tissues and the skin is the recommended practice The severed nerve ends are covered with viable muscle to prevent further nerve damage that may arise from dressings placed in the wound cavity Definitive nerve suture is ideally performed about three to four weeks following injury about two weeks after good healing has been obtained Optimal functional recovery has been found to be obtainable at almost any time up to three months after injury but after six months despite even technically perfect nerve suture the results of suture are almost universally disappointing

ized postoperatively in a plaster of Paris cast in a position that favors maximum relaxation of the anastomosis, etc.

TENDON INJURIES

Tendon injuries are not common in acute simple fractures. They are, however, not at all uncommon as late manifestations of certain simple fractures, particularly Colles' fractures, where late rupture of the extensor pollicis longus tendon may result from fraying through of the tendon by constant trauma against a projecting, irregularly roughened bony surface. They are fairly frequent concomitants of severe crushing and penetrating injuries that are likely to produce compound comminuted fractures.

For the most part, the clinically important traumatic injuries to tendon are to those in the upper extremity, and especially in the hand. Tendon injuries in the lower extremity are infrequent and, when they do occur in the foot, do not produce such serious physiological derangements as do comparable injuries to the tendons of the hand. Indeed, so intricate are the muscle and joint mechanisms of the hand and so disabling are the results of inadequate or even fair reparative surgery that in some centers hand injuries of whatever etiology, or whatever the associated injuries, are treated by hand surgeons and hand surgeons only.

As a general rule, immediate suture of tendons within six hours of injury may be undertaken in all instances except in the presence of severe contamination or massive tissue destruction. Atraumatic asepsis in all phases of wound management is the guiding principle in all tendon surgery. In its absence tendons become adherent and hence functionless.

Tendon surgery should be performed under general or block anesthesia, but never under local infiltration anesthesia. The operative field should be rendered bloodless by the use of a pneumatic tourniquet inflated well above systolic blood pressure. Finely tipped and highly sharpened small instruments must be employed and considerable care should be taken to avoid unnecessary trauma during the course of the operative procedure. The operating surgeon himself should make certain that splints are properly applied and securely fastened postoperatively so as to avoid unnecessary edema and to permit of maximal relaxation of the tendon ends at the site of the anastomosis.

Several different technics are available for tendon repair in varying anatomical locations. In the forearm and on the dorsum of the hand, silk suture is usually followed by good results irrespective of the precise type of anastomosis that is performed. Stainless steel sutures are, however, to be preferred.

Extensor tendons in the forearm or hand may be sutured using as few as possible, usually not more than two, interrupted (No. 35) stainless steel wire sutures fashioned in a figure of eight. The stitch has no particular strength and is placed merely to assure approximation of the severed tendon ends. One loop is inserted into the substance of the tendon, uniting the cut ends, and the second loop is brought out to unite the skin margins. Splinting is most important and in itself is capable of producing adequate re-establishment of tendon continuity, though in not

nized Attention must attend the details of this procedure since determination of the precise level of normally appearing funiculi may avoid subsequent operative intervention and needless hospitalization Frank neuroma formation or the formation of a neuroma-in continuity may result from improper delineation of normally from abnormally arranged funiculi Contrariwise, an unnecessarily prolonged invalidism may result from overzealous debridement since regeneration in peripheral nerves occurs at the usual rate of 1 to 3 mm a day

When normally disposed neural funiculi have been demonstrated in either cut end their proper relationship is secured by applying a hemostat to the partially resected loosely attached nerve slices, which are ultimately to be discarded, and by

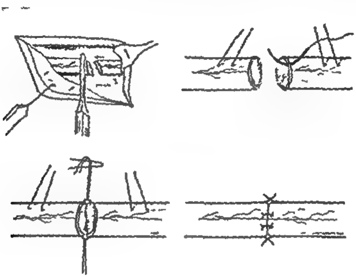


Fig 103 Nerve suture The severed nerve ends are cut sequentially until normal disposition of the neural funiculi is demonstrated Stay sutures are placed in the epineurium and the funiculi are aligned using the longitudinal vessel in each segment as a guide Approximating sutures are then placed circumferentially about the cut ends of the nerve

approximating the hemostat attached to either segment The guide sutures are then gently tensed but not tied to provide additional coaptation A single No 6–0 non absorbable atraumatic suture is then placed through the epineurium about 1 to 2 mm from the cleanly excised nerve ends Another similar suture is placed at one hundred eighty degrees to the first or several similar sutures are placed at ninety or one hundred twenty degree angles to triangulate or quadrangulate the epineurium in a position of axial alignment of the funiculi The partially resected damaged nerve slices are then removed and multiple interrupted No 6–0 atraumatic non absorbable sutures are placed in the epineurium to complete the anastomosis All sutures should be tied with a single square knot and, to obviate unnecessary irritative phenomena, cut directly on the knot The guide sutures are then removed, the tourniquet is deflated and careful hemostasis is secured using as little additional suture material as is possible (Fig 103) Ideally the extremity should be immobil

ized postoperatively in a plaster of Paris cast in a position that favors maximum relaxation of the anastomotic site

Tendon Injuries

Tendon injuries are not common in acute simple fractures They are however, not at all uncommon as late manifestations of certain simple fractures particularly Colles fractures where late rupture of the extensor pollicis longus tendon may result from fraying through of the tendon by constant trauma against a projecting irregularly roughened bony surface They are fairly frequent concomitants of severe crushing and penetrating injuries that are likely to produce compound comminuted fractures

For the most part the clinically important traumatic injuries to tendon are to those in the upper extremity and especially in the hand Tendon injuries in the lower extremity are infrequent and when they do occur in the foot, do not produce such serious physiological derangements as do comparable injuries to the tendons of the hand Indeed, so intricate are the muscle and joint mechanisms of the hand and so disabling are the results of inadequate or even fair reparative surgery that in some centers hand injuries of whatever etiology or whatever the associated injuries are treated by hand surgeons and hand surgeons only

As a general rule, immediate suture of tendons within six hours of injury may be undertaken in all instances except in the presence of severe contamination or massive tissue destruction Atraumatic asepsis in all phases of wound management is the guiding principle in all tendon surgery In its absence tendons become adherent and hence functionless

Tendon surgery should be performed under general or block anesthesia, but never under local infiltration anesthesia The operative field should be rendered bloodless by the use of a pneumatic tourniquet inflated well above systolic blood pressure Finely tipped and highly sharpened small instruments must be employed and considerable care should be taken to avoid unnecessary trauma during the course of the operative procedure The operating surgeon himself should make certain that splints are properly applied and securely fastened postoperatively so as to avoid unnecessary edema and to permit of maximal relaxation of the tendon ends at the site of the anastomosis

Several different technics are available for tendon repair in varying anatomical locations In the forearm and on the dorsum of the hand silk suture is usually followed by good results irrespective of the precise type of anastomosis that is performed Stainless steel sutures are however, to be preferred

Extensor tendons in the forearm or hand may be sutured using as few as possible usually not more than two interrupted (No 35) stainless steel wire sutures fashioned in a figure of-eight The stitch has no particular strength and is placed merely to assure approximation of the severed tendon ends One loop is inserted into the substance of the tendon uniting the cut ends and the second loop is brought out to unite the skin margins Splinting is most important and in itself is capable of producing adequate re-establishment of tendon continuity though in not

nized Attention must attend the details of this procedure since determination of the precise level of normally appearing funiculi may avoid subsequent operative intervention and needless hospitalization Frank neuroma formation or the formation of a neuroma-in-continuity may result from improper delineation of normally from abnormally arranged funiculi Contrariwise, an unnecessarily prolonged invalidism may result from overzealous debridement since regeneration in peripheral nerves occurs at the usual rate of 1 to 3 mm a day

When normally disposed neural funiculi have been demonstrated in either cut end their proper relationship is secured by applying a hemostat to the partially resected, loosely attached nerve slices, which are ultimately to be discarded, and by

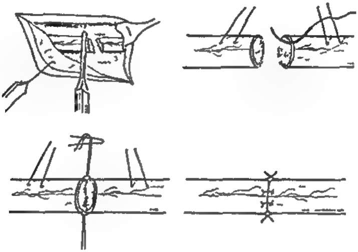


FIG 103 Nerve suture The severed nerve ends are cut sequentially until normal disposition of the neural funiculi is demonstrated Stay sutures are placed in the epineurium and the funiculi are aligned using the longitudinal vessel in each segment as a guide Approximating sutures are then placed circumferentially about the cut ends of the nerve

approximating the hemostat attached to either segment The guide sutures are then gently tensed but not tied to provide additional coaptation A single No 6–0 nonabsorbable atraumatic suture is then placed through the epineurium about 1 to 2 mm from the cleanly excised nerve ends Another similar suture is placed at one hundred eighty degrees to the first or several similar sutures are placed at ninety or one hundred twenty degree angles to triangulate or quadrangulate the epineurium in a position of axial alignment of the funiculi The partially resected damaged nerve slices are then removed and multiple interrupted No 6–0 atraumatic nonabsorbable sutures are placed in the epineurium to complete the anastomosis All sutures should be tied with a single square knot and to obviate unnecessary irritative phenomena cut directly on the knot The guide sutures are then removed the tourniquet is deflated and careful hemostasis is secured using as little additional suture material as is possible (Fig 103) Ideally the extremity should be immobil-

ized postoperatively in a plaster of Paris cast in a position that favors maximum relaxation of the anastomotic site

TENDON INJURIES

Tendon injuries are not common in acute, simple fractures They are, however, not at all uncommon as late manifestations of certain simple fractures particularly Colles fractures, where late rupture of the extensor pollicis longus tendon may result from fraying through of the tendon by constant trauma against a projecting irregularly roughened bony surface They are fairly frequent concomitants of severe crushing and penetrating injuries that are likely to produce compound comminuted fractures

For the most part the clinically important traumatic injuries to tendon are to those in the upper extremity and especially in the hand Tendon injuries in the lower extremity are infrequent and when they do occur in the foot, do not produce such serious physiological derangements as do comparable injuries to the tendons of the hand Indeed, so intricate are the muscle and joint mechanisms of the hand and so disabling are the results of inadequate or even fair reparative surgery that in some centers hand injuries of whatever etiology or whatever the associated injuries are treated by hand surgeons and hand surgeons only

As a general rule, immediate suture of tendons within six hours of injury may be undertaken in all instances except in the presence of severe contamination or massive tissue destruction Atraumatic asepsis in all phases of wound management is the guiding principle in all tendon surgery In its absence tendons become adherent and hence functionless

Tendon surgery should be performed under general or block anesthesia, but never under local infiltration anesthesia The operative field should be rendered bloodless by the use of a pneumatic tourniquet inflated well above systolic blood pressure Finely tipped and highly sharpened small instruments must be employed and considerable care should be taken to avoid unnecessary trauma during the course of the operative procedure The operating surgeon himself should make certain that splints are properly applied and securely fastened postoperatively so as to avoid unnecessary edema and to permit of maximal relaxation of the tendon ends at the site of the anastomosis

Several different technics are available for tendon repair in varying anatomical locations In the forearm and on the dorsum of the hand, silk suture is usually followed by good results irrespective of the precise type of anastomosis that is performed Stainless steel sutures are, however, to be preferred

Extensor tendons in the forearm or hand may be sutured using as few as possible usually not more than two interrupted (No 35) stainless steel wire sutures fashioned in a figure of eight The stitch has no particular strength and is placed merely to assure approximation of the severed tendon ends One loop is inserted into the substance of the tendon uniting the cut ends, and the second loop is brought out to unite the skin margins Splinting is most important and in itself is capable of producing adequate re-establishment of tendon continuity though in not

so elegant a manner as can be obtained by suture and splinting The hand must be immobilized in a position of hyperextension on a well padded volar splint that extends from the tip of the dorsal aspect of the distal phalanx well up on to the fore arm and maintained in this position for three weeks After this time, the sutures are removed and gradually progressive exercises begun to reinstitute motion in the fingers

In contradistinction to the dorsal surface, silk suture methods on the volar surface of the hand are virtually universally doomed to failure, owing to constant irritation, edema, inflammation and fibrosis secondary to angulation and movement of

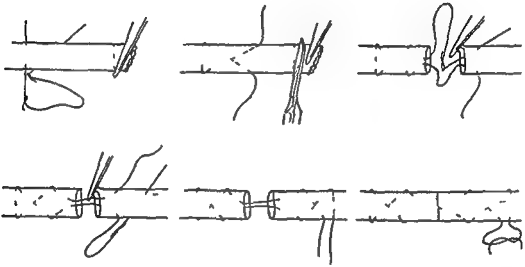


FIG 104 Tendon suture The Bunnel stitch is passed through the proximal end of the severed tendon The frayed cut ends of the tendon are cleanly excised and the two ends of the suture are passed through the center of the proximal segment The same procedure but in the reverse order is employed for completion of the anastomosis

*tendons within their sheaths Fine stainless steel wire provokes the least tissue reac*tion of all presently available suture materials and affords the most efficacious material for tendon suture These wires should be removed after three weeks at which time practically all tendons will have physiologically though not anatomically healed

Flexor tendons severed in the forearm or in the palm proximal to the distal inch of the palm (the distal palmar crease) may be approximated using the Bunnell stitch The principal feature of this technic is that the proximal portion of the severed tendon is actively brought into approximation with the passive distal cut end by tension on its proximal portion and muscle belly

The proximal end of the distal segment is trimmed and a finely tipped hemostat is placed at the distal end of the proximal segment for stabilizing purposes Using a one foot length of No 35 stainless steel wire, each end of which is attached to a straight needle one needle is passed transversely through the substance of the proximal segment 1 cm proximal to its cut end The needle is then passed obliquely back and forth through the tendon two or three times at roughly forty five degree angles Just before the needle emerges from the cut end of the tendon the tendon is

trimmed immediately proximal to the stabilizing clamp by means of sharp scissors or a scalpel The needle is then passed through the cleanly divided end of the tendon The second needle is then passed through the tendon in opposite directions until both ends of the wire pass through the central portion of the cut proximal end The two ends of the wire are then pulled taut and each needle is passed through the

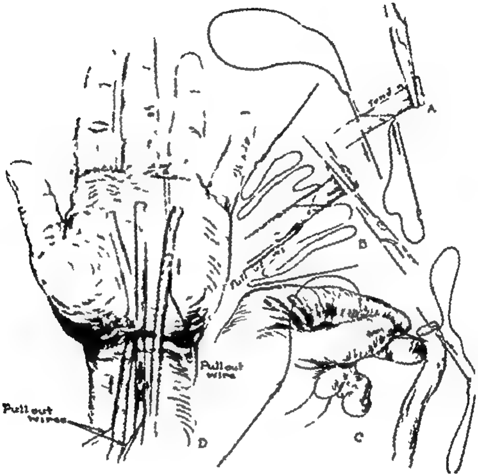


FIG 105 Pull-out technic for tendon suture A Bunnel stitch is passed through the proximal segment of the severed tendon after incorporating a pull-out stitch which is passed through the skin proximally The distal ends of the suture are then passed through the skin and tied over a button making sufficient tension to permit end to-end apposition of the severed tendon ends (Reproduced from Bunnell S *Surgery of the Hand* 3rd ed J B Lippincott Co Philadelphia 1956)

central portion of the distal segment of the tendon for a distance of several centimeters and then carried out through the surface of that tendon The ends of the wire are then tied over the distal end of the tendon (Fig 104) These sutures are left in situ

If it is desired to remove the sutures a pull out wire about six inches long is placed through the loop on the proximal side of the tendon repair and passed out through the skin The ends of the suture that transfix the distal portion of the tendon are passed through the skin and tied over a button on the skin surface (Fig 105)

so elegant a manner as can be obtained by suture and splinting The hand must be immobilized in a position of hyperextension on a well-padded volar splint that extends from the tip of the dorsal aspect of the distal phalanx well up on to the forearm and maintained in this position for three weeks After this time, the sutures are removed and gradually progressive exercises begun to reinstitute motion in the fingers

In contradistinction to the dorsal surface, silk suture methods on the volar surface of the hand are virtually universally doomed to failure, owing to constant irritation edema inflammation, and fibrosis secondary to angulation and movement of

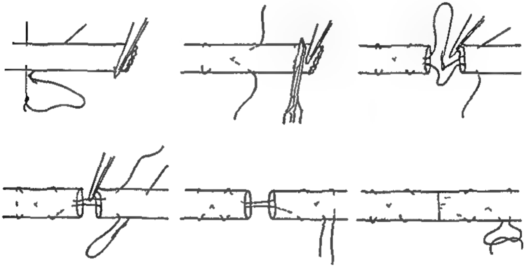


FIG 104 Tendon suture The Bunnel stitch is passed through the proximal end of the severed tendon The frayed cut ends of the tendon are cleanly excised and the two ends of the suture are passed through the center of the proximal segment The same procedure but in the reverse order is employed for completion of the anastomosis

tendons within their sheaths Fine stainless steel wire provokes the least tissue reaction of all presently available suture materials and affords the most efficacious material for tendon suture These wires should be removed after three weeks, at which time practically all tendons will have physiologically though not anatomically healed

Flexor tendons severed in the forearm or in the palm proximal to the distal inch of the palm (the distal palmar crease) may be approximated using the Bunnell stitch The principal feature of this technic is that the proximal portion of the severed tendon is actively brought into approximation with the passive distal cut end by tension on its proximal portion and muscle belly

The proximal end of the distal segment is trimmed and a finely tipped hemostat is placed at the distal end of the proximal segment for stabilizing purposes Using a one-foot length of No 35 stainless steel wire each end of which is attached to a straight needle one needle is passed transversely through the substance of the proximal segment 1 cm proximal to its cut end The needle is then passed obliquely back and forth through the tendon two or three times at roughly forty-five degree angles Just before the needle emerges from the cut end of the tendon the tendon is

trimmed immediately proximal to the stabilizing clamp by means of sharp scissors or a scalpel The needle is then passed through the cleanly divided end of the tendon The second needle is then passed through the tendon in opposite directions until both ends of the wire pass through the central portion of the cut proximal end The two ends of the wire are then pulled taut and each needle is passed through the

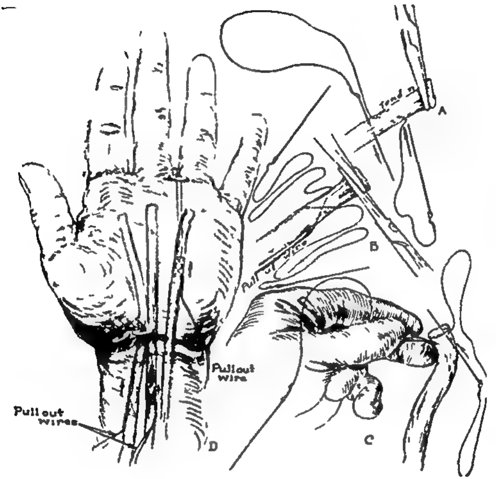


FIG 105 Pull out technic for tendon suture A Bunnel stitch is passed through the proximal segment of the severed tendon after incorporating a pull out stitch which is passed through the skin proximally The distal ends of the suture are then passed through the skin and tied over a button making sufficient tension to permit end to end apposition of the severed tendon ends (Reproduced from Bunnell S *Surgery of the Hand* 3rd ed J B Lippincott Co Philadelphia 1956)

central portion of the distal segment of the tendon for a distance of several centimeters and then carried out through the surface of that tendon The ends of the wire are then tied over the distal end of the tendon (Fig 104) These sutures are left in situ

If it is desired to remove the sutures a pull out wire about six inches long is placed through the loop on the proximal side of the tendon repair and passed out through the skin The ends of the suture that transfix the distal portion of the tendon are passed through the skin and tied over a button on the skin surface (Fig 105)

An alternate and quicker method of suturing flexor tendons in the forearm or palm is afforded by the Bunnel double right angle stitch The needle is passed directly through the proximal end of the tendon, near its severed end, and then through the distal end The suture is then passed through the distal end of the tendon at right angles to the previous stitch, and then through the proximal portion in the same plane Only then are both ends of the suture tied Where infection is feared *a pull-out stitch may be incorporated in either of the loops in the proximal* portion of the tendon and passed through the skin If the wound heals per primam, the pull-out stitch is removed leaving the double right angle suture in place

Flexor tendons severed within or distal to what Bunnell has called no man's land, the region between the distal palmar crease and the point of insertion of the flexor digitorum sublimis tendon into the middle phalanx, in which both the flexor sublimis and flexor profundus tendons share a common sheath, pose particularly serious problems Tendon injuries in the hand are most frequent in this location and the results of suture here are undeniably worst The Bunnell suture-at a distance method of repair is probably the best, but good results follow in only about 40 per cent of all attempts at suture even under ideally favorable conditions This technic essentially involves holding the proximal severed tendon end distally by placing a pull out suture in the proximal end of the tendon and tying the wires over a skin button placed several centimeters proximal to the site of the tendon lesion One or at most, two nonabsorbable sutures of the finest arterial silk (No 6–0) may be used if indicated, to assure approximation of the severed ends (Fig 106)

Where the flexor sublimis and profundus tendons are injured at or near the same level and there is fear that there may be cicatricial union between the two tendons it is better to sacrifice the sublimis and to depend upon re establishment of continuity in the profundus tendon for ultimate motion of the finger Flexor tendons severed in the palm proximal to entering the flexor sheaths over the metacarpal heads should be individually sutured but care must be taken to separate the sublimis from the profundus tendons by the interposition of the lumbrical muscles

In wounds neither anatomically nor bacteriologically favorable when first seen primary suture of a ruptured tendon should be deferred The anastomosis will not heal and ultimate damage both from additional surgical trauma and infection tends to be greater than would have resulted had the wound undergone careful debridement delayed closure by pedical skin grafts, and maintenance of bone length preferably by transcortical fixation devices Definitive tendon surgery should be delayed in such circumstances until one or two weeks after the covering pedicle graft has been divided (i e about four to six weeks after the graft has been placed) so as to assure maximal circulatory integrity of the overlying skin

At secondary operation tendons in the fingers can be readily located by means of a mid-laterally placed incision Digital incisions, however should not pass proximally beyond the flexion crease of the metacarpophalangeal joint lest flexion contractures and tendon adhesions result Additional exposure for recovery of tendons may be obtained by either bayonet Z-shaped, or transverse incisions made more proximally Passive flexion of the fingers facilitates recovery by causing

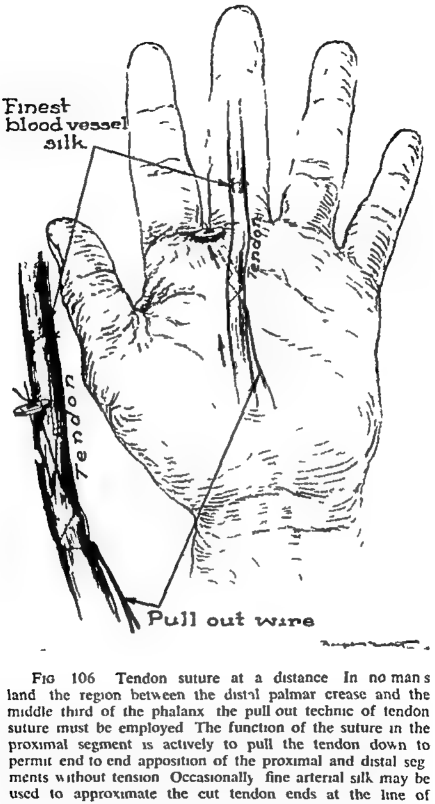


FIG 106 Tendon suture at a distance In no man s land the region between the distal palmar crease and the middle third of the phalanx the pull out technic of tendon suture must be employed The function of the suture in the proximal segment is actively to pull the tendon down to permit end to end apposition of the proximal and distal seg ments without tension Occasionally fine arterial silk may be used to approximate the cut tendon ends at the line of anastomosis though this is frequently not necessary and often undesirable (Reproduced from Bunnell S *Surgery of the Hand* 3rd ed J B Lippincott Co Philadelphia 1956)

protrusion of the distal cut end of a tendon and pressure on its muscle belly will tend to cause protrusion of the proximal severed end

When large defects in tendons are found either at initial debridement or secondary operation, no attempt should be made by the casual tendon surgeon at primary grafting procedures In some instances, it may be possible to obtain free grafts of the palmaris longus or the flexor sublimis tendons without any difficulty, but it is unquestionably better for the patient to enlist the aid of a specially equipped hand surgeon to complete any such primary grafting procedures

Skin Defects

Wounds anatomically and bacteriologically favorable should be closed primarily Wounds in which the possibility of infection exists are better managed by delayed than by primary closure

During debridement of the local wound, care should be taken to preserve as much viable skin and subcutaneous tissue as is compatible with the bacteriological requirements of the wound Circular skin defects should be avoided and, wherever possible, small wounds with relatively little loss of substance should be converted into elliptical oblong or triangular defects In regions where the skin is freely mobile and does not directly overlie bone or tendons, an adequate functional and cosmetic result can usually be obtained without subjecting the suture line to undue tension Where tension is likely to be exerted on the line of suture, it may be overcome by extending the incision longitudinally by undermining of the adjacent margins of the skin flaps, and, if necessary, by the making of relaxing counterincisions parallel to the lateral margins of the wound

Wounds that cannot be directly approximated or areas of large skin defect may be permitted to close by granulation and scar tissue formation or may be closed by the preparation and placing of properly selected skin grafts Skin grafts may be either split or full-thickness free grafts or full thickness pedical grafts

Split thickness free grafts are usually divided into three types depending upon the thickness of the graft (1) thin split-thickness grafts, 0 005 to 0 010 inches in depth which *consist primarily of epidermis* (2) *intermediate thickness grafts* 0 010 to 0 022 inches in depth which contain the stratum papillare of the corium as well as the epidermis and (3) thick split-thickness grafts 0 022 to 0 030 inches in depth which contain the epidermis the stratum papillare and about half the stratum reticulare of the corium

In general there is a direct relationship between the thickness of a free graft and the probability of its take despite superficial contamination and insecure hemostasis of the recipient site The thinner grafts have a tendency to change color, contract fissure or ulcerate and are therefore not desirable for skin coverage following compound fractures The full thickness grafts are precarious in their take and frequently necrose Intermediate split thickness free grafts have therefore found the widest use Since they possess a dermal pad with numerous interlacing elastic fibrils they have more resiliance than do the thinner grafts and are more likely to take than are the full thickness free grafts

Split thickness free grafts may be obtained either freehand, using a long-bladed sharp knife, or by any one of several types of dermatome The host area is prepared and draped in the usual manner and the skin is tensed in a direction opposite to that of the blade used to obtain the graft When a dermatome is used the skin surface is painted with a specially prepared glue The skin graft is obtained using long broad sweeps of the skin knife or the dermatome blade, taking care that the leading margin of the knife is slightly elevated to prevent an uneven or full thickness graft After removal of the graft, the host area is protected by a fine mesh paraffin- or petrolatum impregnated gauze and is later dressed

It is preferable to employ free grafts in large sheets Pinch or stamp grafts have only very little usefulness Because of the scarring between the islands of regenerating epithelium, the donor site cannot be used for the taking of subsequent grafts and the recipient site is almost always cosmetically and functionally unsatisfactory

At the time of their application the full sheets of the free grafts are laid upon the recipient area, moistened with a little saline and smoothed flat To accommodate for contraction, the graft should be made slightly larger and overlap the margins of the defect to be covered The graft is fixed to the skin margins by stay sutures on atraumatic needles that penetrate the graft first and then the margin of the defect After these have been placed blood clots and other material that may be on the surface of the recipient site are removed manually or by gentle irrigation with small amounts of saline The margins of the graft are then securely fixed to the edges of the defect by interrupted stay sutures The sutures should be left long after tying for later fixation of a stent dressing over the surface of the graft

No useful purpose is served by puncturing the graft Except over a bleeding point it has no value for drainage, and where hemorrhage exists the graft will not take Basting stitches may be employed to fix the graft in position, but this purpose can be better satisfied by applying a sponge rubber or moistened gauze stent dressing over the paraffined gauze used to protect the graft Neither the donor nor recipient site should be disturbed for at least four days postoperatively unless there is evidence of infection

Cosmetically and functionally free grafts are not as desirable as pedicle grafts Free grafts usually lack sufficient durability for the ordinary daily trauma to which the extremities are usually subjected and they are virtually always incapable of withstanding the rigors imposed by the necessity for subsequent reconstructive surgery For this reason pedicle flaps with their blood supply intact are to be preferred in the closure of large skin defects associated with compound fractures

Pedicle flaps in which the full thickness of the dermis and all or varying portions of the subcutaneous fat pad are transplanted, may be performed as direct grafts or as tube grafts

Direct flaps may be of the local or cross limb varieties Local flaps, transplanted from adjacent tissues are most efficacious where indicated and are unquestionably the most easily performed They are usually of limited usefulness in that they cannot be employed to cover most large defects They are, however ideally suited to the closure of relatively small defects in regions where the skin and subcutaneous

tissues are freely mobile and where the donor site is not likely to break down when closed primarily or by means of a free split-thickness graft

Three different methods of local flap transplantation are available (1) advancement, (2) rotation, and (3) sliding Advancement and rotation flaps are unipedicled while the sliding type is bipedicled Advancement is obtained by undercutting the area of skin to be transplanted and simply attaching its free margin to the opposite side of the skin defect Rotation involves essentially the same maneuver except that after undermining, the flap is rotated around its base and fitted into the defect leaving behind an area that must be covered by free split-thickness grafts The sliding, bipedicled graft is fashioned by the making of an incision parallel to the long axis of the skin defect at a distance from its margin equal to the width of the defect The flap is released by longitudinally extending the edges of the wound adjacent to the skin flap The bipedicled graft is then undermined raised from the deep fascia, and sutured to the margins of the original skin defect The secondary defect thus produced may be closed either by free split-thickness grafts or by the making of relaxing counterincisions and primary closure The wound is dressed and left untouched for a period of two to three weeks

Where skin grafting is necessary as a preliminary to the treatment of nonunion or other reconstructive surgery unsatisfactory skin coverage may be supplanted either by a cross-limb pedicle graft or by a tubed pedicle graft

Cross-limb pedicle grafts are performed for defects of the lower third of the leg and foot which can be readily brought into contact with the medical portion of the opposite calf or anteromedial aspect of the opposite thigh In the upper extremity, the trunk forms a more suitable donor site than does the opposite extremity

Careful preoperative planning constitutes the most important phase in any cross limb procedure The limb to be grafted must be placed in proximity to the donor site and must be capable of firm fixation for the period of time necessary for the graft to acquire a new blood supply If the length of the graft is not more than two or two *and a half times its base, the flap can be cut and applied directly to the* recipient area If there is any doubt as to the integrity of the circulation at the tip of the graft however it is probably safer to perform the operation in two stages, forming a bipedicled flap and cutting free the margin to be transplanted at the end of about two weeks

The optimum position for placing of the graft and for the comfort of the patient must be determined preoperatively and if desired appropriately windowed plaster of Paris immobilizing casts may be prepared at this time If not the limbs may be immobilized at the time that the graft is performed

As in the sliding or rotating types of local flap the secondary defect of the donor site may be closed by split-thickness graft before the edge of the cross-limb flap is fixed to the margin of the recipient skin defect The free undersurface of the pedicle flap may be protected by a free split thickness skin graft or by simple dressing The limbs are then immobilized and held together in the plaster of Paris casts which are not disturbed for a period of at least three weeks (Fig 107)

Before transecting the base of the cross limb pedicle the integrity of the newly acquired circulation must be determined either by constricting the base of the graft or by the histamine test The latter is performed by obstructing the circulation at

the base of the pedicle by a rubber-shod clamp and injecting 0 1 ml of a 1 1,000 histamine solution intradermally into several regions both in the normal and transplanted tissue If there is no appreciable difference in the rate of wheal formation in the several areas it may be assumed that the circulation is adequate and the base

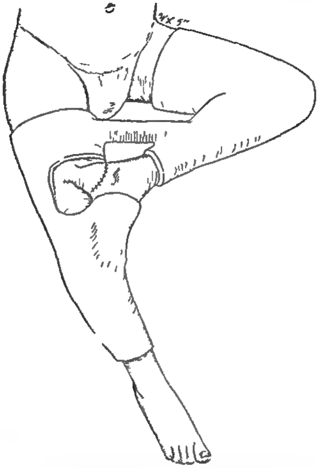


Fig 107 Cross leg pedicle flap A pedicle flap from the anterior surface of the thigh has been applied to the heel of the left foot Both limbs have been immobilized in a single plaster cast The cast has been windowed to permit observation of the pedicle flap (Modified from Milch H Resection of arsenical epithelioma Plastic reconstruction of the heel *Am J Surg 16* 89 1932)

of the pedicle may be transected with impunity Where there is an appreciable difference in the rate of wheal formation however it is safer to delay freeing of the pedicle

Where the location or the size of the skin defect makes cross limb transplantation inadvisable tube pedicle grafts may be used As with other skin-grafting procedures preoperative planning is essential particularly since one or more transplantations may be necessary It is of the utmost importance that the length of any proposed tube be not greater than two and a half times its width

At operation, two parallel lines, not more than two and a half times the width between them, and with gently flared ends, are marked on the skin with methylene blue Three or four perpendicular cross marks are then made at identical positions on either long limb In order to facilitate later closure of the secondary defects at either end of the tube, one limb of the proposed incision is made at a slightly higher level than the other and on the side toward which the freed tube will later be rotated The skin is then incised along each of the longitudinal lines down to the deep fascia The bipedicled flap thus produced is undermined, the skin margins are rolled into a tube and stay sutures are placed at the crosshatched lines previously made After careful hemostasis the subcutaneous tissues are approximated by interrupted or continuous sutures and the skin margins are approximated by multiple interrupted sutures The secondary skin defect formed beneath the tube is closed by wide undermining of its edges and direct suture or by free skin grafting

The wound of the secondary defect should be lightly dressed but the tube pedicle requires no dressing other than that necessary to support its mid portion To discourage edema in the tubed pedicle a lined ice pack may be placed over the pedicle for the first twenty-four to forty eight hours but should be discontinued after this time Sutures in the pedicle should not be removed for two to three weeks but, if indicated sutures in the donor site may be removed earlier Transection of one end of the tube and its transfer to another site is performed about three weeks after the operation provided that the integrity of the circulation has been determined by either the compression or histamine tests

By repeating this procedure, using each end of the tubed pedicle alternately, a defect at a considerable distance from the original donor site may be surfaced After the tube has been replaced in the recipient site the redundant pedicle may be either discarded or used as a local flap to close one or more of the secondary defects produced during its transfer

Combined Injuries

Although each of the various technics here mentioned has been considered as an isolated procedure a combination of any one or several of these is most likely to occur in association with a compound fracture The treatment of each of the soft tissue injuries may on occasion be at cross purposes with one another and with the treatment of the open fracture It becomes important, therefore to determine the order of precedence of treatment Generally speaking it is most important of course to maintain the integrity of the circulation and if possible this should be done without loss of the over all length of the injured bone The treatment of the vascular injury and the closure of the skin defect take precedence over the treatment of nerve or tendon injuries which may be performed at some time after the acute situation has been adequately managed Where conditions are entirely favorable all the procedures may be undertaken at the time of primary surgery In this circumstance transcortical or intramedullary fixation devices may be used to immobilize the bone so as to permit positioning of the extremity for ideal treatment of the associated soft tissue injuries

CHAPTER 9

Regional Anesthesia in Fracture Treatment

By Herbert D Dubovsky

Anesthesia for use in the treatment of fractures is determined by as many variable factors as are the surgical procedures that may be indicated It is obviously neither feasible nor practical to attempt here any complete discussion of all the procedures that may meet all fracture needs Most of the agents and technics of general, epidural, and spinal anesthesia have been omitted from the present discussion They require the presence of a trained anesthesiologist and the use of specialized anesthesia equipment The technics and agents described in the present section, therefore are those that illustrate the fundamental principles and approaches of conductive anesthesia

Fundamentally conductive anesthesia depends upon the impedance of axonal conduction distal to the site of application or introduction of the anesthetic agent When *nerve endings* are anesthetized by infiltration or topical technics the type of anesthetic method is known as infiltration or topical block They may be applied at a single locus or may involve a circumscribed area of the surface of the body, in which instance the name field or ring block is usually applied When the anesthetic drug is introduced at any point along the course of a *nerve* the resulting anesthesia is called a nerve block and when into the region of the various intervertebral foramina a paravertebral block The spinal nerves also be blocked in the *epidural space* in epidural blocks or in the *subarachnoid space* in spinal anesthesia

Numerous so-called local anesthestic agents are used in each of these anesthetic technics All possess certain common chemical physical and physiological properties They all tend to have (1) a selective pharmacological action that is confined to neural tissues (2) little if any adverse affect upon adjacent tissues (3) physiological reversibility of their action (4) a profound stimulating effect on

At operation, two parallel lines, not more than two and a half times the width between them, and with gently flared ends are marked on the skin with methylene blue Three or four perpendicular cross marks are then made at identical positions on either long limb In order to facilitate later closure of the secondary defects at either end of the tube, one limb of the proposed incision is made at a slightly higher level than the other and on the side toward which the freed tube will later be rotated The skin is then incised along each of the longitudinal lines down to the deep fascia The bipedicled flap thus produced is undermined the skin margins are rolled into a tube and stay sutures are placed at the crosshatched lines previously made After careful hemostasis the subcutaneous tissues are approximated by interrupted or continuous sutures and the skin margins are approximated by multiple interrupted sutures The secondary skin defect formed beneath the tube is closed by wide undermining of its edges and direct suture or by free skin grafting

The wound of the secondary defect should be lightly dressed but the tube pedicle requires no dressing other than that necessary to support its mid portion To discourage edema in the tubed pedicle a lined ice pack may be placed over the pedicle for the first twenty-four to forty-eight hours but should be discontinued after this time Sutures in the pedicle should not be removed for two to three weeks but if indicated sutures in the donor site may be removed earlier Transection of one end of the tube and its transfer to another site is performed about three weeks after the operation provided that the integrity of the circulation has been determined by either the compression or histamine tests

By *repeating this procedure, using each end of the tubed pedicle alternately* a defect at a considerable distance from the original donor site may be surfaced After the tube has been replaced in the recipient site, the redundant pedicle may be either discarded or used as a local flap to close one or more of the secondary defects produced during its transfer

Combined Injuries

Although each of the various technics here mentioned has been considered as an isolated procedure a combination of any one or several of these is most likely to occur in association with a compound fracture The treatment of each of the soft tissue injuries may on occasion, be at cross purposes with one another and with the treatment of the open fracture It becomes important therefore, to determine the order of precedence of treatment Generally speaking it is most important of course to maintain the integrity of the circulation and if possible this should be done without loss of the over-all length of the injured bone The treatment of the vascular injury and the closure of the skin defect take precedence over the treatment of nerve or tendon injuries which may be performed at some time after the acute situation has been adequately managed Where conditions are entirely favorable all the procedures may be undertaken at the time of primary surgery In this circumstance transcortical or intramedullary fixation devices may be used to immobilize the bone so as to permit positioning of the extremity for ideal treatment of the associated soft tissue injuries

CHAPTER 9

Regional Anesthesia in Fracture Treatment

By Herbert D Dubovsky

Anesthesia for use in the treatment of fractures is determined by as many variable factors as are the surgical procedures that may be indicated It is obviously neither feasible nor practical to attempt here any complete discussion of all the procedures that may meet all fracture needs Most of the agents and technics of general, epidural and spinal anesthesia have been omitted from the present discussion They require the presence of a trained anesthesiologist and the use of specialized anesthesia equipment The technics and agents described in the present section, therefore, are those that illustrate the fundamental principles and approaches of conductive anesthesia

Fundamentally conductive anesthesia depends upon the impedance of axonal conduction distal to the site of application or introduction of the anesthetic agent When *nerve endings* are anesthetized by infiltration or topical technics, the type of anesthetic method is known as infiltration or topical block They may be applied at a single locus or may involve a circumscribed area of the surface of the body, in which instance the name field or ring block, is usually applied When the anesthetic drug is introduced at any point along the course of a *nerve* the resulting anesthesia is called a nerve block and when into the region of the various intervertebral foramina a paravertebral block The spinal nerves also be blocked in the *epidural space* in epidural blocks or in the *subarachnoid space* in spinal anesthesia

Numerous so-called local anesthestic agents are used in each of these anesthetic technics All possess certain common chemical physical and physiological properties They all tend to have (1) a selective pharmacological action that is confined to neural tissues (2) little if any adverse affect upon adjacent tissues, (3) physiological reversibility of their action (4) a profound stimulating effect on

the central nervous system, followed by depression leading to death, when administered systemically in large doses, (5) a spasmolytic effect on smooth muscle, (6) a tendency to cause arteriolar dilatation, with the exception of the one naturally occurring material, cocaine, which is a vasoconstrictor, and (7) a tendency to increase the refractory period, raise the threshold for stimulation, and prolong the conduction time of cardiac muscle.

Despite their extensive application in clinical medicine, very little is known about the mechanism of action of the local anesthetic drugs, though something has been learned concerning the relationship of anesthetic activity to chemical structure. Of the several theories the most generally accepted hypothesis of the mode of action is that such compounds render axonal conduction impossible by preventing the phasic depolarization and repolarization of cell membranes. Structurally local anesthetic for the most part are tertiary aminoesters of aromatic acids and either aliphatic or alicyclic alcohols. They are basic substances, owing to the presence of the amino nitrogen group, and their aqueous solutions are bitter-tasting and alkaline, except when prepared in the hydrochloride form.

Most of the commonly used agents, furthermore, are substituted derivatives of para aminobenzoic acid, in which the aliphatic alcohol residue either may remain unsubstituted (as in benzocaine) or may possess an amino group, usually on the terminal carbon atom (as in procaine and its derivatives). In general, increasing the length of the ester chain not only increases the anesthetic potency, but also the agent's toxicity. Certain less complex alcohols also possess anesthetic effects. In general, however, agents such as the phenols and cresols and certain cyclic alcohols are of value only for topical anesthesia.

A clinically useful characteristic of local anesthetic agents is that their undesirable systemic effects may be mitigated by the prophylactic administration of hypnotic drugs, especially the barbiturates.* Furthermore, since the duration of action of the local anesthetic drugs is proportional to the time interval during which they remain in contact with neural tissues, and since most are arteriolar dilators, it is often desirable to prolong their action by the concomitant administration of vasoconstricting agents. The sympathomimetic amines are of particular importance in this regard. Epinephrine and Cobefrin are especially useful not only in prolonging the direct effects of anesthetics, but also in diminishing the rate of their disappearance and, therefore, in reducing the likelihood of untoward systemic effects.

Epinephrine, 1:200,000, or Cobefrin, an isomer of epinephrine, in 1:40,000 or 1:80,000 dilution may be employed with the calculated dose of a local anesthetic agent. *Under no circumstance, however, should a vasoconstricting agent be employed in digital blocks, lest irreversible vasoconstriction with ischemia and gangrene supervene.*

* The administration of barbiturates will not protect the patient against all the possible ill effects of local anesthetic agents. The barbiturates will mitigate only the irritative or stimulative effects of the local drugs on the central nervous system. When there is a depression of the circulatory system, the barbiturates only tend to compound the ill effects, and treatment must be directed toward support of the circulatory system by vasopressors and intravenous fluids.

The agents commonly employed for local blocks are listed in Table 2. The figures represent the maximum volume of dosage that, for average adults, should not be exceeded at the designated concentrations of each of the drugs.

As implied previously, toxic reactions to anesthetic drugs may be caused by several factors. The most important of these is overdosage of the drug following accidental intravascular injection or injection into an area rich in blood supply, which favors rapid absorption. Excessive amounts of anesthetic solution or too rapid a rate of injection of a single dose may produce relative overdosage, especially in elderly or debilitated individuals whose ability to detoxify the drug is impaired. Individual idiosyncrasy and inadequate premedication must also be considered.

TABLE 2.—LOCAL ANESTHETIC AGENTS IN COMMON USE

Name	Synonym	Use and dosage: Nerve block	Use and dosage: Field block	Hours average duration action
Procaine	Novocaine	1% (100 ml.) 2% (50 ml.)	0.5% (100-200 ml.)	0.5-1.5
Pontocaine	Tetracaine	0.1% (50 ml.) max. 1 mg./kg.	Not recommended	2-4
Metycaine	Piperocaine	1.5% (50 ml.)	1% (75 ml.)	1-1.5
Lidocaine	Xylocaine	2% (30 ml.) 1% (50 ml.)	0.5% (75 ml.)	1-2
Chloroprocaine	Nesacaine	3% (30 ml.) 2% (50 ml.) 1% (75 ml.)	0.5% (100 ml.)	2-3
Hexylcaine	Cyclaine	2% (30 ml.) 1% (50 ml.)	0.5% (75 ml.)	1-2

NOTE. The numbers in parentheses represent the *maximum* volume of dosage that, for average adults, should not be exceeded at the designated concentrations.

Toxic reactions may be classified into those that primarily affect the central nervous system by stimulation and those that depress the circulation. Central stimulation may be of a mild type, in which the patient exhibits restlessness, apprehension and fright, or of a more severe degree in which twitching of small muscles progresses to convulsions and respiratory difficulties. Prolonged stimulation will eventually lead to depression of the vital centers, unconsciousness and death. This toxic reaction depends on the blood level of the drug and that in turn depends upon the amount injected and the rapidity of its destruction by circulating esterases.

Circulatory depression, the second type of reaction, is characterized by pallor, hypotension, bradycardia or arrythmia and may be accompanied by allergic responses. The latter are sometimes designated as true idiosyncrasies and may be clinically manifested by an eczematous dermatosis, acute asthma or anaphylactic shock and sudden death. For this reason it is often advisable to employ intradermal skin tests (using saline as a control) to determine hypersensitivity phenomena before administering any local anaesthetic. Where hypersensitivity is exhibited, sub

stitution of another compound having local anesthetic properties but possessing a sufficiently different chemical configuration may usually be employed without difficulty, since cross-sensitization to compounds having different chemical configurations is allegedly rare. In any event, patients should be questioned as to any prior episodes of idiosyncrasies to the drug that it is intended to employ.

Treatment of toxic reactions includes oxygen inhalation by mask, with assisted respirations if breathing is depressed. Intravenous injection of a short acting barbiturate (Pentothal or Surital) in repeated doses of 50 to 100 mg. will control convulsions. Vasopressors and intravenous fluids should be used to support the circulation if depression predominates.

Prevention of toxic reactions includes the use of adequate premedication with barbiturates and/or narcotic and belladonna drugs. Only the smallest amount and minimum concentration of drug necessary for the contemplated block should be used. A vasopressor mixed with the anesthetic solution will prevent excessively rapid absorption, especially in highly vascular areas. Intravenous injection may be avoided by aspirating in two planes before injection.

TECHNICS OF LOCAL ANESTHESIA

All local anesthetic procedures should be preceded by adequate premedication of the patient, appropriate cleansing of the skin area, and the actual injection must be carried out under strict aseptic conditions.

The control of causalgic pain or the relief of vasospasm may be accomplished by blockade of the regional paravertebral sympathetic ganglia or by blockade of the nerves that supply specific areas. In the upper extremity, sympathetic blockade involves particularly anesthesia of the stellate ganglion; in the lower extremity, anesthesia of the lumbar sympathetic chain.

SYMPATHETIC GANGLION BLOCKADE

Stellate Ganglion Block

Stellate ganglion block is employed to relieve vasospasm and causalgic pain in the upper extremity, face, and head. The ganglion may be approached either anteriorly, posteriorly, or laterally. The anterior approach is simplest and is to be preferred. The patient is placed in the supine position with a pillow beneath the shoulders so as to extend the head. The sternoclavicular junction, the carotid artery, and the trachea are identified by palpation. A skin wheal is raised two finger breadths (5 cm.) above the sternoclavicular junction at a point between the trachea and the carotid artery. With the index finger, the carotid artery is displaced laterally and a twenty four-gauge needle, 5 cm. in length, is advanced slowly in a posterior direction until bone is contacted. The needle is then withdrawn about 0.5 cm. and 10 ml. of anesthetic solution are injected, after making certain that the needle has not entered a blood vessel. For adequate blockade of the arm and hand, the injection should be made with the patient in the seated position and 20 ml. of the anes-

thetic agent should be employed Downward gravitation of the fluid will effect anesthesia of the inferior cervical ganglion as well as the first, second, and third thoracic ganglia

A successful block is evidenced within five to ten minutes by the appearance of a Horner s syndrome (narrowing of the palpebral fissure, miosis, enophthalmos, and increased skin temperature)

Complications of stellate ganglion block include pneumothorax, hemorrhage, high spinal anesthesia, and perforation of the esophagus

Pneumothorax will occur if pleurae and lung are pierced It is of no special consequence if recognized at once and the needle be removed immediately The patient should lie down with the head slightly elevated, and should be given sedation adequate for the control of pain He should be carefully watched for the appearance of a tension pneumothorax, if this develops, prompt removal of the excessive air by syringe and needle or underwater catheter drainage is the treatment of choice

Hemorrhage from puncture of a vertebral artery may occur, but, unless severe, is of no consequence and requires no special treatment

High spinal anesthesia may follow an accidental spinal tap If the patient exhibits symptoms of a high spinal anesthesia (dyspnea, depressed respiration, hypotension, high level of skin anesthesia, tingling of the fingers, etc) prompt treatment is essential to save the patient s life This includes adequate support of respiration with oxygen using a mask and a rebreathing bag, intravenous fluids, vasopressors to support the failing circulation and withdrawal of 20 to 40 ml of spinal fluid

Penetration of the esophagus is an occasional accident The patient will cough taste the anesthetic solution, and complain of constriction in the throat Extending the head before attempting the block will pull the esophagus behind the trachea and so minimize the likelihood of accidental esophageal puncture If the esophagus is entered however, antibiotics should be given prophylactically to forestall the possibility of infection and the subsequent development of an esophageal fistula

Lumbar Paravertebral Block

Lumbar paravertebral sympathetic block is used to produce vasodilatation and to relieve pain in the lower extremity The patient is placed in the prone position with a pillow beneath the abdomen to flex the lumber vertebrae The spinous processes of the second and third lumbar vertebrae are palpated (the spinous process of the fourth lumbar vertebra is at the level of the iliac crest) A skin wheal is raised two and a half fingerbreadths (5 cm) lateral to the spinous process of the second lumbar vertebra A twenty two-gauge needle, 10 cm long is then inserted perpendicularly to the skin until it strikes the transverse process of the second lumber vertebra at a depth of approximately 4 to 5 cm The needle is then redirected medially and cephalad so that it slips off the transverse process and points toward the vertebral body It is advanced an additional 4 to 5 cm until its beveled edge slips off the anterolateral surface of the vertebral body The needle is withdrawn 0 5 cm and 10 ml of the anesthetic solution are injected The same procedure is then repeated at the level of the third and fourth lumbar vertebrae

Complications of paravertebral block include intrathecal injection, resulting in a spinal anesthetic, puncture of a major vessel such as the aorta or the vena cava, or penetration of an intraabdominal organ The former can be avoided by not inclining the needle toward the vertebral body at too acute an angle and the latter by not advancing the needle too far If there is any suspicion of puncture of a hollow viscus prophylactic antibiotics should be administered

PERIPHERAL NERVE BLOCKADE UPPER EXTREMITY

In the upper extremity, peripheral nerve blockade may be accomplished by anesthetizing the brachial plexus the suprascapular nerve and the median ulnar radial or musculocutaneous as well as digital nerves

Brachial Plexus Block

Brachial plexus block is employed to accomplish anesthesia of the entire upper extremity It is particularly useful for the performance of surgery in the forearm and hand (Fig 108)

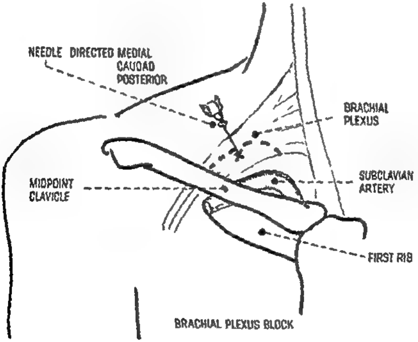


Fig 108 Brachial plexus block The needle is inserted about 2 cm above the mid point of the clavicle and is directed medially caudad and posteriorly for a distance of not more than 3 cm

The supraclavicular approach ■ the easiest and the most successful With the patient in the supine position ■ sandbag is placed between the scapulae so that the shoulder of the side to be blocked is depressed and the head is turned toward the

opposite side The subclavian artery is palpated at the point where the external jugular vein crosses the clavicle The vessel is depressed medially and downward by the left index finger and a skin wheal is raised one fingerbreadth (2 cm) above the mid point of the clavicle A twenty-two gauge needle, 8 cm in length, directed medially, caudad, and posteriorly, is then advanced carefully until paresthesias are elicited or the first rib encountered In no event should the needle be advanced beyond 3 cm to avoid puncture of the apex of the pleura and the production of a peumothorax A 10 ml Luer-Lok syringe is then attached and aspiration is attempted in two planes If paresthesias are elicited and no blood is obtained, 10 ml of the anesthetic solution are slowly injected Additional amounts, to make a total of 30 to 40 ml may be introduced just medial and lateral to the site of initial injection

If no paresthesias are elicited, the needle may be advanced until the first rib is encountered It is then withdrawn 0 5 cm (the level of the fascial plane of the brachial plexus) and 10 ml of anesthetic solution are injected An additional 10 ml are injected as the needle is withdrawn The needle is then reinserted twice so that its point will lie just posteromedial and posterolateral to the site of the initial injection Similar amounts of the anesthetic agents are introduced at each of these sites so that a total of 40 to 60 ml of the anesthetic are introduced in a fanwise direction between the first rib and the subcutaneous tissues

Anesthesia will develop within fifteen to thirty minutes after completion of the block and will last from one to four hours depending upon the agent employed Motor paralysis is unusual, so that the patient can often help the surgeon in identification of specific tendons by motion of designated fingers

Complications of brachial plexus block include pneumothorax and blood vessel puncture The former usually results from too rapid or carelessly deep insertion of the needle It may be treated by bed rest morphine sedation, oxygen, and, if severe, by aspiration of air from the pleural cavity Blood vessel puncture is usually not serious and may be treated by merely withdrawing the needle and applying pressure for several minutes After bleeding has ceased the block may be continued

Suprascapular Nerve Block

This local anesthetic technic is used in the treatment of painful conditions about the shoulder With the patient in a seated position the scapula is made prominent by placing the hand upon the opposite shoulder The spine of the scapula is then readily palpable along its entire length A line is drawn perpendicular to the spine at its mid point (Fig 109) The upper and outer angle formed by this perpendicular line is bisected by a second line and at a point 1 5 cm along this second line a skin wheal is raised A twenty two-gauge needle 8 cm long is inserted through the wheal and is directed medially anteriorly and slightly caudad until bone is struck This usually occurs at a point just lateral to the suprascapular notch The needle is then withdrawn 0 5 cm and reinserted in a slightly more medial direction In this manner the needle can be walked along the supraspinatus fossa until the

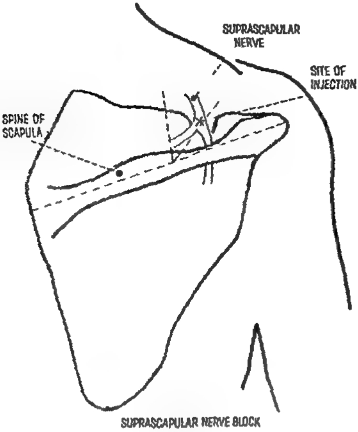


FIG 109 Suprascapular block A perpendicular line is drawn to the mid point of the spine of the scapula The upper and outer angle thus formed is bisected and at a point 1 5 cm along this line the needle is directed medially anteriorly, and slightly caudad until bone is struck

notch is located Contact with the suprascapular nerve is indicated by the appearance of paresthesias radiating to the shoulder Ten ml of anesthetic solution are then injected in this area avoiding intravascular injection

Elbow Blocks

Elbow blocks are used mainly for sympathetic block and diagnosis but brachial plexus block is more satisfactory for hand and forearm surgery In those individuals in whom brachial block is difficult because of a short thick neck or is contraindicated because of injury or the presence of local infection blocking of the median radial and ulnar nerves at the elbow may be used

Median Nerve Block

The median nerve may be blocked at the elbow in the following manner the elbow is flexed to ninety degrees and at the point where the skin of the forearm meets that of the arm, a transverse line is marked in the crease thus formed When

the arm is extended this line will be found to lie 2 to 3 cm above the skin fold of the antecubital fossa The biceps tendon the brachial artery, and the medial humeral condyle are palpated A skin wheal is raised on the previously marked line, medial to the brachial artery and midway between the biceps tendon and the medial humeral condyle A twenty-five-gauge needle, 5 cm in length, is inserted perpendicularly to the skin and advanced slowly until paresthesias are obtained If bone is contacted before paresthesias are noted, the needle should be withdrawn slightly and reintroduced in a more medial direction Paresthesias must be elicited in all blocks at the elbow in order to obtain satisfactory anesthesia Eight to 10 ml of the anesthetic agent are slowly injected

Radial Nerve Block

Radial nerve block at the elbow may be accomplished by raising a skin wheal 1 cm lateral to the lateral margin of the biceps tendon on the transverse line drawn previously as for median nerve block The needle is inserted perpendicularly and advanced until paresthesias are obtained Eight to 10 ml of anesthetic solution are then slowly injected

Musculocutaneous Nerve Block

Musculocutaneous nerve block at the elbow may be achieved after completion of the radial nerve block As the needle is withdrawn slightly it is redirected medially beneath the biceps tendon (the musculocutaneous nerve lies between the biceps tendon and the brachioradialis) Eight to 10 ml of anesthetic are then infiltrated into this region

Ulnar Nerve Block

The ulnar nerve may be blocked at the elbow as it lies in the groove between the medial condyle of the humerus and the olecranon process Over this groove, at the level of the line drawn previously around the arm a skin wheal is raised and a twenty-five gauge needle 5 cm in length is directed downward into the groove Penetration of the fascia covering the groove and contact with the ulnar nerve will be evidenced by the appearance of paresthesias Five milliliters of the anesthetic solution should then be injected

Wrist Blocks

Wrist blocks may be employed for surgery of the hand (Fig 110) Since the radial nerve divides into its terminal branches 3 to 4 inches above the wrist only the median and ulnar nerves need be blocked at the wrist The level at which these nerves may be injected is indicated by the proximal palmar crease of the wrist This corresponds approximately to the level of the ulnar styloid process and a line is drawn at this level across the volar aspect of the wrist The median nerve lies between the palmaris longus tendon and the tendon of the flexor carpi radialis These tendons may be identified by having the patient flex the wrist against re-

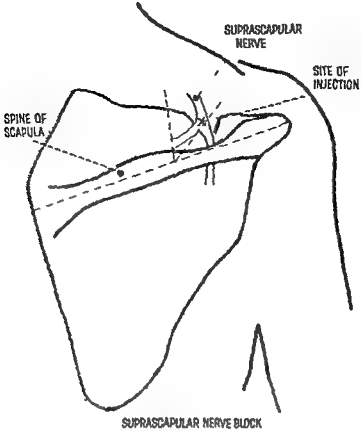


FIG 109 Suprascapular block A perpendicular line is drawn to the mid point of the spine of the scapula The upper and outer angle thus formed is bisected and at a point 1 5 cm along this line the needle is directed medially anteriorly and slightly caudad until bone is struck

notch is located Contact with the suprascapular nerve is indicated by the appearance of paresthesias radiating to the shoulder Ten ml of anesthetic solution are then injected in this area avoiding intravascular injection

Elbow Blocks

Elbow blocks are used mainly for sympathetic block and diagnosis, but brachial plexus block is more satisfactory for hand and forearm surgery In those individuals in whom brachial block is difficult because of a short thick neck or is contraindicated because of injury or the presence of local infection, blocking of the median, radial and ulnar nerves at the elbow may be used

Median Nerve Block

The median nerve may be blocked at the elbow in the following manner the elbow is flexed to ninety degrees and at the point where the skin of the forearm meets that of the arm a transverse line is marked in the crease thus formed When

pated Between the metacarpal bones and 2 cm proximal to the metacarpal heads, a skin wheal is raised A twenty-four-gauge needle, 5 cm long, is inserted directly downward until its tip is palpated on the palmar surface and 3 ml of anesthetic solution are injected As the needle is withdrawn an additional 7 ml are injected This will serve to anesthetize the adjacent surfaces of two fingers If all of one finger is to be anesthetized, a similar procedure must be employed in the neighboring intermetacarpal space Before the needle is completely withdrawn it should be directed into the web between the fingers, which is infiltrated with 3 ml of the anesthetic

Individual phalanges of the fingers can be anesthetized by injecting 2 ml of the anesthetic solution from bone to skin on each side proximal to the site of surgery (Fig 110)

PERIPHERAL NERVE BLOCKADE
LOWER EXTREMITY

In the lower extremity peripheral nerve blockade may be accomplished by anesthetizing the sciatic nerve the femoral, the lateral femoral cutaneous, the peroneal and the tibial nerves

Sciatic Nerve Block

To block the sciatic nerve, the patient is placed in a modified Sim s position and rolled slightly forward so that the side to be blocked is uppermost, with the thigh flexed to about one hundred and thirty-five degrees A line is drawn between the greater trochanter and the posterior-superior iliac spine At its mid-point a second line, 3 cm long and inferior to the first, is drawn at right angles to the first A skin wheal is raised at the end of the second line and a twenty-two gauge needle, 10 cm long is slowly advanced until paresthesias are produced Ten to 15 ml of anesthetic solution are deposited here Care must be taken to avoid intraneural injection since this may lead to shock and neuralgia owing to pressure necrosis of the nerve This block produces anesthesia of the posterior thigh, leg and foot

Femoral Nerve Block

Femoral nerve block is performed with the patient in the supine position The femoral artery is palpated 2 to 3 cm below the inguinal ligament At this level a wheal is raised just lateral to the artery The artery is then displaced medially and a twenty two gauge needle 5 cm long is perpendicularly inserted through the wheal and advanced until paresthesias are elicited Ten ml of anesthetic solution are injected at this level Femoral nerve block produces anesthesia of the anterior and medial aspects of the thigh

Lateral Femoral Cutaneous Nerve Block

With the patient in the supine position the anterior-superior spine of the ilium is palpated and a wheal is raised 2 cm superior and medial to the spine The

sistance Between these two tendons and on the line previously drawn a skin wheal is raised and a twenty-five gauge needle, 5 cm long is inserted and advanced until paresthesias are elicited Five to 10 ml of anesthetic solution are then injected

The ulnar nerve may be located by raising a wheal just lateral to the tendon of the flexor carpi ulnaris on the previously drawn transverse line A twenty five gauge needle 5 cm long is introduced through the wheal and slowly advanced until paresthesias are elicited Five ml of the anesthetic drug are then administered

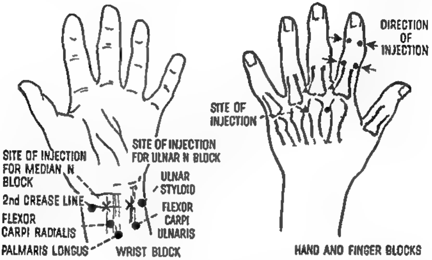


FIG 110 Wrist and hand blocks Wrist blocks are accomplished by blockade of both the median and ulnar nerves The hand is placed in the palm up position The ulnar nerve is anesthetized by introducing the needle at the level of the ulnar styloid process just lateral to the tendon of the flexor carpi ulnaris muscle For injection of the median nerve the needle is inserted at the level of the proximal palmar crease of the wrist in the plane of the middle finger between the tendons of the palmaris longus and the flexor carpi radialis muscles Finger blocks may be accomplished by intermeta carpal injections or by direct injection of the area of the laterally placed digital nerves

The terminal branches of the radial nerve can be blocked by infiltrating an intradermal and subcutaneous ring around the wrist at the level of the line previously drawn from the ulnar styloid

HAND BLOCKS

Hand blocks are useful in surgery of the fingers (Fig 110) It is particularly important to remember that epinephrine or other vasoconstricting substance should not be mixed with the anesthetic solution so as to obviate irreversible vasospasm No more than the required amount of anesthetic solution should be employed since the excessive pressure that this produces may also result in gangrene

With the hand placed palm downward the heads of the metacarpals are pal-

pated Between the metacarpal bones and 2 cm proximal to the metacarpal heads, a skin wheal is raised A twenty-four gauge needle, 5 cm long is inserted directly downward until its tip is palpated on the palmar surface and 3 ml of anesthetic solution are injected As the needle is withdrawn an additional 7 ml are injected This will serve to anesthetize the adjacent surfaces of two fingers If all of one finger is to be anesthetized, a similar procedure must be employed in the neighboring intermetacarpal space Before the needle is completely withdrawn it should be directed into the web between the fingers, which is infiltrated with 3 ml of the anesthetic

Individual phalanges of the fingers can be anesthetized by injecting 2 ml of the anesthetic solution from bone to skin on each side proximal to the site of surgery (Fig 110)

PERIPHERAL NERVE BLOCKADE
LOWER EXTREMITY

In the lower extremity peripheral nerve blockade may be accomplished by anesthetizing the sciatic nerve, the femoral the lateral femoral cutaneous, the peroneal and the tibial nerves

Sciatic Nerve Block

To block the sciatic nerve the patient is placed in a modified Sim's position and rolled slightly forward so that the side to be blocked is uppermost with the thigh flexed to about one hundred and thirty five degrees A line is drawn between the greater trochanter and the posterior superior iliac spine At its mid-point a second line, 3 cm long and inferior to the first, is drawn at right angles to the first A skin wheal is raised at the end of the second line and a twenty-two gauge needle, 10 cm long is slowly advanced until paresthesias are produced Ten to 15 ml of anesthetic solution are deposited here Care must be taken to avoid intraneural injection since this may lead to shock and neuralgia owing to pressure necrosis of the nerve This block produces anesthesia of the posterior thigh, leg and foot

Femoral Nerve Block

Femoral nerve block is performed with the patient in the supine position The femoral artery is palpated 2 to 3 cm below the inguinal ligament At this level a wheal is raised just lateral to the artery The artery is then displaced medially and a twenty two gauge needle 5 cm long is perpendicularly inserted through the wheal and advanced until paresthesias are elicited Ten ml of anesthetic solution are injected at this level Femoral nerve block produces anesthesia of the anterior and medial aspects of the thigh

Lateral Femoral Cutaneous Nerve Block

With the patient in the supine position the anterior-superior spine of the ilium is palpated and a wheal is raised 2 cm superior and medial to the spine The

sistance Between these two tendons and on the line previously drawn a skin wheal is raised and a twenty five-gauge needle, 5 cm long, is inserted and advanced until paresthesias are elicited Five to 10 ml of anesthetic solution are then injected

The ulnar nerve may be located by raising a wheal just lateral to the tendon of the flexor carpi ulnaris on the previously drawn transverse line A twenty five gauge needle, 5 cm long is introduced through the wheal and slowly advanced until paresthesias are elicited Five ml of the anesthetic drug are then administered

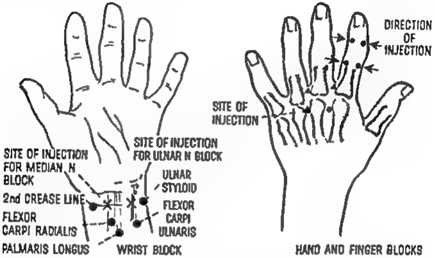


Fig 110 Wrist and hand blocks Wrist blocks are accomplished by blockade of both the median and ulnar nerves The hand is placed in the palm up position The ulnar nerve is anesthetized by introducing the needle at the level of the ulnar styloid process just lateral to the tendon of the flexor carpi ulnaris muscle For injection of the median nerve the needle is inserted at the level of the proximal palmar crease of the wrist in the plane of the middle finger between the tendons of the palmaris longus and the flexor carpi radialis muscles Finger blocks may be accomplished by intermeta carpal injections or by direct injection of the area of the laterally placed digital nerves

The terminal branches of the radial nerve can be blocked by infiltrating an intradermal and subcutaneous ring around the wrist at the level of the line previously drawn from the ulnar styloid

Hand Blocks

Hand blocks are useful in surgery of the fingers (Fig 110) It is particularly important to remember that epinephrine or other vasoconstricting substance should not be mixed with the anesthetic solution so as to obviate irreversible vasospasm No more than the required amount of anesthetic solution should be employed since the excessive pressure that this produces may also result in gangrene

With the hand placed palm downward the heads of the metacarpals are pal-

pated Between the metacarpal bones and 2 cm proximal to the metacarpal heads a skin wheal is raised A twenty-four gauge needle 5 cm long is inserted directly downward until its tip is palpated on the palmar surface and 3 ml of anesthetic solution are injected As the needle is withdrawn an additional 7 ml are injected This will serve to anesthetize the adjacent surfaces of two fingers If all of one finger is to be anesthetized, a similar procedure must be employed in the neighboring intermetacarpal space Before the needle is completely withdrawn it should be directed into the web between the fingers, which is infiltrated with 3 ml of the anesthetic

Individual phalanges of the fingers can be anesthetized by injecting 2 ml of the anesthetic solution from bone to skin on each side proximal to the site of surgery (Fig 110)

PERIPHERAL NERVE BLOCKADE LOWER EXTREMITY

In the lower extremity peripheral nerve blockade may be accomplished by anesthetizing the sciatic nerve the femoral the lateral femoral cutaneous the peroneal and the tibial nerves

Sciatic Nerve Block

To block the sciatic nerve the patient is placed in a modified Sim s position and rolled slightly forward so that the side to be blocked is uppermost with the thigh flexed to about one hundred and thirty-five degrees A line is drawn between the greater trochanter and the posterior-superior iliac spine At its mid point a second line 3 cm long and inferior to the first is drawn at right angles to the first A skin wheal is raised at the end of the second line and a twenty-two gauge needle 10 cm long is slowly advanced until paresthesias are produced Ten to 15 ml of anesthetic solution are deposited here Care must be taken to avoid intraneural injection since this may lead to shock and neuralgia owing to pressure necrosis of the nerve This block produces anesthesia of the posterior thigh leg and foot

Femoral Nerve Block

Femoral nerve block is performed with the patient in the supine position The femoral artery is palpated 2 to 3 cm below the inguinal ligament At this level a wheal is raised just lateral to the artery The artery is then displaced medially and a twenty two gauge needle 5 cm long is perpendicularly inserted through the wheal and advanced until paresthesias are elicited Ten ml of anesthetic solution are injected at this level Femoral nerve block produces anesthesia of the anterior and medial aspects of the thigh

Lateral Femoral Cutaneous Nerve Block

With the patient in the supine position the anterior superior spine of the ilium is palpated and a wheal is raised 2 cm superior and medial to the spine The

needle is then directed laterally and inferiorly until bone is contacted Five ml of anesthetic solution are injected and an additional 10 ml are introduced as the needle is withdrawn The needle is then reinserted and anesthetic solution is injected in a fanwise manner medial and inferior to the anterior-superior iliac spine This results in *anesthesia of the anterolateral aspect of the thigh*

Nerve Block for Open Reduction of Fractured Neck of the Femur

Regional anesthesia for the treatment of this condition is indicated for those elderly and debilitated patients whose condition contraindicates general anesthetics (Fig 111)

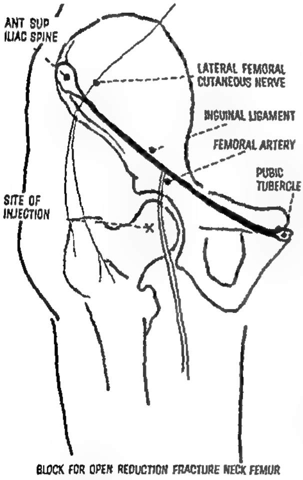


Fig 111 Block for femoral neck fracture The needle is inserted at a point 3 cm below the mid point of the inguinal ligament More complete anesthesia may be obtained by simultaneously blocking the lateral femoral cutaneous and sciatic nerves (*See text*)

With the patient in the supine position a line is drawn between the anterior superior spine of the ilium and the pubic tubercle At a point 3 cm below the mid point of this line (the inguinal ligament) a wheal is raised and a twenty two gauge needle 5 cm long, is inserted until contact with the head of the femur is achieved The needle is withdrawn slightly and after making certain that the point of the needle is not in a vessel 30 ml of anesthetic solution are slowly injected Subcutaneous *and intracutaneous infiltration along the inguinal ligament is performed* to block the superficial skin nerves and the lateral femoral cutaneous nerve is

blocked at the anterior-superior iliac spine as previously described The line of the skin incision is infiltrated separately to provide more profound anesthesia

Common Peroneal Nerve Block

Blockade of the common peroneal nerve is of value in the treatment of painful conditions of the leg and foot The patient is placed in a lateral position and the groove below the head of the fibula in which the common peroneal nerve lies, is palpated The nerve can usually be felt to roll under the fingers subcutaneously A skin wheal is raised just below the fibular head and a twenty five-gauge needle, 3 cm long is inserted perpendicular to the skin and advanced cautiously until paresthesias are elicited Five ml of solution are injected

If no paresthesias are elicited 10 ml of solution are used to infiltrate the tissues down to the bone in three directions

Tibial Nerve Block

Blockade of this nerve at the knee when combined with a block of the common peroneal nerve and intracutaneous and subcutaneous infiltration around the leg below the knee permit surgical intervention upon the leg and foot

The nerve can be located in the following manner with the patient in a prone position the leg is flexed to ninety degrees on the thigh and a transverse line is drawn at the point where the skin of the calf meets that of the thigh The leg is then extended and the popliteal artery is palpated at a point about 2 cm cephalad to the line A skin wheal is raised just lateral to the popliteal artery, at the level of the line and a twenty-two-gauge needle 5 cm long is inserted perpendicular to the skin The needle is advanced slowly until paresthesias are elicited and 5 to 10 ml of anesthetic solution are injected If no paresthesias are produced the needle may be introduced in a fanlike direction until such paresthesias are obtained Care must be exercised to avoid intravascular injection or injury to the popliteal vessels which lie in close proximity to the nerve

For operations on the foot alone, the anterior and posterior tibial nerves can be blocked at the level of the ankle joint For blockade of the posterior tibial nerve a wheal is raised at the level of the medial malleolus medial to the Achilles tendon A twenty five-gauge needle 5 cm long is slowly introduced until paresthesias are elicited or bone is contacted Five milliliters of anesthetic solution are injected at this point and an additional 5 ml are injected as the needle is withdrawn

The anterior tibial nerve lies between the tibialis anticus tendon (medially) and the extensor hallucis longus tendon (laterally) A wheal is raised between these two tendons at the level of the medial malleolus and a twenty five-gauge needle 5 cm long is introduced until paresthesias are elicited or bone is contacted Five ml of anesthetic solution are injected at this point and an additional 10 ml are injected as the needle is withdrawn

Additional subcutaneous and intracutaneous injection of anesthetic agent

around the leg just above the malleoli will block all sensory fibers of the femoral nerve to the foot and result in more profound anesthesia

Digital Nerve Blocks

Anesthesia of the toes may be accomplished by injecting between the metatarsal heads in the same manner as injection between the metacarpal heads for digital nerve blocks in the upper extremity

Nerve Blocks for Long Bone Fractures

Relief of pain in a fractured long bone may be obtained by injecting 20 to 30 ml of 1 per cent procaine or an equivalent amount of another local anesthetic agent, directly into the hematoma at the fracture site In fresh fractures presence of the needle in the hematoma will be manifested by a spurt of blood into the barrel of the syringe The anesthetic should be injected slowly Hyaluronidase may be added to the anesthetic solution to facilitate its dispersion within the hematoma Within about ten minutes the area is usually adequately anesthetized to permit of traction or other manipulative procedures In heavily muscled individuals additional infiltration of the muscles about the fracture is usually necessary to secure sufficient relaxation

Nerve Block for Chest Injuries

Relief of pain following injuries to the thoracic cage may be obtained by (1) intercostal nerve block (2) direct injection into the fracture site and (3) para vertebral somatic block The latter two methods have been discussed previously

Intercostal Nerve Block

The lower border of the rib is palpated in the mid axillary line, the point of origin of the anterior and posterior intercostal nerves A twenty five-gauge needle 5 cm long is inserted through the skin without a skin wheal and advanced along the course of the rib hugging the lower border of the rib with the point of the needle Ten ml of anesthetic solution are injected as the needle is withdrawn

By an alternate technic the rib is palpated at the mid-axillary line and a twenty-five gauge needle 3 cm long is inserted perpendicularly to the rib When the bone is contacted, the needle is withdrawn slightly and its point is slipped beneath the edge of the rib by pulling the skin downward with the needle When the point slips beneath the edge of the rib 5 ml of anesthetic solution are injected To avoid the possibility of a pneumothorax the needle should not be advanced more than 0 5 cm beyond the anterior margin of the rib

SECTION II

The Axial Skeleton

Fractures of the axial skeleton differ from those of the appendicular skeleton in that they affect primarily short, flat bones More particularly, however they differ in that they may affect vital visceral structures, such as the brain the spinal cord, the thoracic or abdominal viscera

Generally speaking the care of injuries to these structures, which may be life threatening takes precedence over the treatment of the fracture Insofar as the associated soft tissue injuries fall within the field of interest of specialized surgical technics they should be treated entirely by or at least in collaboration with a specialist in the particular field While a fracture of the skull is to be sure a bone injury, it is the possibility of damage to the underlying brain rather than the fracture that calls for urgent treatment A simple fracture of the spine or of the pelvis may very well lie within the province of the fracture surgeon but in the presence of a paraplegia, a ruptured rectum, or urinary extravasation, the fracture surgeon however extensive his experience, will be best advised to seek the advice and co operation of the neurosurgeon, the general surgeon, or the urologist

Fractures of the skull and fractures of the facial bones are subject to such special problems and methods of treatment that they fall automatically into the field of the neurological or maxillofacial surgeon A discussion of these fractures therefore has been purposely omitted

Fractures of the remainder of the axial skeleton uncomplicated by visceral injuries lie properly within the purview of the fracture surgeon These injuries may be grouped as comprising (1) fractures of the spinal column and (2) fractures of the thoracic cage

CHAPTER 10

Fractures of the Vertebral Column

Fractures of the vertebrae acquire their urgency primarily because of the possibility of concomitant damage to the spinal cord or the adjacent spinal nerves Where there is evidence of such involvement, treatment should be a joint concern of the fracture surgeon and the neurosurgeon

TREATMENT OF THE PATIENT

Fractures of the spine vary in their potential danger to the underlying neural tissues depending upon the location and type of the fracture and the portion of the vertebra that is fractured Simple flexion (compression) fractures of the body of the cervical vertebrae are more apt to lead to cord damage than fractures in other regions because of the relative narrowness of the cervical spinal canal Injuries to the cord in the thoracic region are more apt to result from depressed fractures of the neural arch and from fracture dislocations than from simple compression fractures Fractures in the lower lumbar region may lead to impairment of bladder and bowel function as a consequence of injury to the cauda equina or the lower sacral roots

Care of the patient in whom a vertebral fracture is suspected must begin from the moment of injury The patient should be cautioned against independent motion Any change in position, even for the purpose of transportation, should be undertaken only with the aid of at least three assistants The patient should be moved in one piece and all motions of the first-aid team should occur at the same time, so as to avoid unnecessary or jerky motion Unless unconscious the patient should be placed in the supine position with the feet and ankles bound together Narcotics should not be administered unless specifically indicated for the control of intractable nerve root pain If the patient is unconscious and the lesion is not in the cervical spine the prone position may be employed for transportation if facilities for tracheal suction are not available Where the lesion is in the cervical spine, however the patient must be transported in the supine position irrespective of his state of consciousness The same precautions must be observed with respect to motion of

the patient even after he has been admitted to the hospital emergency room The subsequent care of the patient will depend upon whether or not there is evidence of involvement of the central nervous system

In acutely paraplegic patients with suspected vertebral fractures, care must be directed toward the evaluation of other possible visceral injuries before any diagnostic or therapeutic measures are undertaken with respect to the fracture itself Where none exist, specific attention must be given to the prevention of bladder or bowel overdistension The patient should be immediately catheterized and placed on constant urinary drainage until such time as more direct care can be given to the bladder Where paralytic ileus exists an intestinal tube should be inserted, but if this tube does not pass spontaneously through the pylorus no efforts should be made to expedite its passage by change of position Suction and appropriate parenteral fluid therapy should be instituted at the earliest possible moment When these measures have been completed, other diagnostic studies, specifically x ray examination may be undertaken as indicated provided that the patient is not further moved

In many instances of acute spinal cord injury spinal shock may be present This clinical syndrome is characterized by a loss of all somatic and visceral reflexes, flaccid paralysis, total loss of all modalities of sensation distal to the site of the injury, and hyperesthesia or other irritative phenomena immediately proximal to the lesion that may be due either to complete transection, to severe contusion or to concussion of the spinal cord Though hypotension and tachycardia may be present as a result of the associated loss of vasomotor reflexes there is classically no loss of blood volume such as is characteristic of hemorrhagic shock from which uncomplicated spinal shock is to be clearly differentiated

In the acute stage, it is often impossible clearly to differentiate between those cases in which paraplegia results from anatomical transection of the cord and those resulting from physiological interruption of the neurological pathways by edema or hemorrhage Occasionally however a clinical distinction between these two conditions can be made

Complete transections are characterized by immediate onset of a symmetrical and total flaccid paralysis of all muscles below the level of the suspected injury Voluntary motion is abolished Reflex reactions cannot be elicited muscle tone disappears and all sensation is lost The extremities are cold and cyanotic and sweating is inhibited in contradistinction to what is usually seen in hemorrhagic shock where sweating is profuse In partial transection or severe contusion and concussion of the cord on the other hand the sensory and motor phenomena are characteristically asymmetrical A variable amount of voluntary motion may be present and the sensory loss may be only partial Indeed the patient often complains of pain paresthesia and other irritative phenomena in various parts of the limbs Reflex reactions may be only partly abolished The Babinski extensor response is usually preserved and this is of good prognostic significance

While the differentiation may be of some value from a prognostic point of view it is of vastly greater importance in determining the indication for surgical intervention In cases of complete transection the cord is irreparably damaged

and nothing can be expected from surgery. On the other hand, partial lesions of the cord may be due to localized pressure defects in which laminectomy may be of vital importance.

Attention has been directed to the fact that laminectomy is of value only in relieving pressure caused by anatomical blocking of the spinal canal. Where the roentgenogram presents indisputable evidence of depressed fragments of bone within the spinal canal, laminectomy is immediately indicated. Where, however, such evidence is lacking, the problem will be more difficult of resolution. It has been shown that persistent edema of the cord may in itself lead to permanent paralysis and the question is, therefore, that of differentiating between spinal fluid block resulting from edema and that caused by actual mechanical obstruction. Lumbar puncture and the performance of manometric tests have been recommended as a method of making this differentiation. Unfortunately, this is not the case, since a block resulting from edema may give exactly the same response as that from mechanical block precisely within the forty-eight hours or so following injury when it is important to make the differentiation. Similarly, mechanical obstruction such as may arise from a depressed bone fragment may exist without any evidence of spinal fluid block.

If there is any roentgenographic evidence of irreducible mechanical compression of the cord, laminectomy is indicated and lumbar puncture will add nothing to the indications. Cord compression resulting from edema will usually subside or show evidence of subsidence within the first several days after injury. A lumbar puncture performed during this time adds little to any diagnosis, may lead to additional injury to already damaged cord structures, and by altering the dynamic conditions within the subarachnoid space, may increase edema or bleeding. Although persistent spinal fluid block is rare in cases in which there is no x-ray evidence of mechanical obstruction, unchanged paraplegic symptoms for more than three to four days after an acute injury justify the performance of a lumbar puncture.

The presence of a spinal fluid block with evidence of hemorrhage, crenated red cells, or xanthochromic discoloration after a nontraumatic lumbar puncture is suggestive either of subarachnoid hemorrhage or crushing injury to the cord and justifies the performance of an exploratory laminectomy. The presence of a spinal fluid block without evidence of recent hemorrhage is suggestive of edema or concussion of the cord that will not be benefited by laminectomy.

Apart from compound fractures, the primary indications for the performance of laminectomy after acute injury to the vertebral column in the presence of paraplegia are (1) the existence of an irreducible fracture or fracture dislocation with obvious roentgen evidence of cord compression, (2) the existence of depressed bone spicules within the spinal canal, and (3) the existence of a spinal fluid block with evidence of recent subarachnoid bleeding.

Wherever possible, even the paraplegic patient should be treated conservatively. The most important part of the conservative treatment of such patients is the care of the bladder, the rectum, and the skin.

Immediately following the incidence of a spinal cord injury there is usually complete loss of bladder control and development of a cord bladder. At the outset,

when all reflexes have been abolished, the cord bladder is of the atonic type As signs of spinal shock gradually subside, there is restoration of autonomous control of the bladder, through neural mechanisms situated within the bladder musculature This type of autonomous bladder is characteristically succeeded by the hypertonic bladder in which spinal reflexes are re-established and is followed by the uninhibited cord bladder that is the end result in all cases of complete transections of the spinal cord In partial transections, further restoration of bladder control may proceed to the point where the bladder differs but slightly in detrussor power from the normal

In lesions of the sacrum, where the possibility of re-establishment of spinal reflexes is precluded by the destruction of the pudendal nerves, the end result will be the autonomous bladder In complete transections of the cord the result will be the uninhibited cord bladder and in all other lesions a relatively normal cord bladder will be the result The gradual rehabilitation of the bladder from the atonic bladder characteristic of the stage of spinal shock and subject to the level of the spinal cord lesion will depend upon the degree of care that is given to the bladder This will be determined in large part by the care exerted to avoid distension of the bladder wall and is therefore, intimately associated with accurate measurement of the detrussor power of the bladder

The work of Munro in developing the concept of tidal drainage in all disturbances of bladder function is fundamental in the treatment of these patients Tidal drainage is applied to all cases of cord bladder and is essential to bladder rehabilitation It is accomplished by means of a relatively simple apparatus the essential part of which is the ability to adjust the automatic siphonage of the bladder at a level consistent with the power of the detrussor muscle (Table 3) In the atonic bladder the average tonus of the destrussor is not greater than can overcome a column of saline of about 2 cm above the level of the symphysis pubis As the destrussor power increases the height of the column of fluid is increased and the tidal drainage is continued until such time as the patient is able to empty the bladder completely against pressure

In addition to care of the bladder attention must be directed to prevention and treatment of paralytic ileus in the stage of spinal shock This may be accomplished where indicated by intestinal intubation by the administration of cholinergic drugs and later by feeding In the later stages obstipation and fecal impaction are frequently troublesome Fecal impaction should be carefully avoided by the use of mineral oil and enemas and if present should be removed digitally

The care of the skin is most important Attention must be sedulously directed toward keeping the patient dry at all times Wherever possible the patient should be turned frequently to prevent the formation of decubiti and all measures save the use of the oscillating bed indicated for the management of acute arterial occlusion should be instituted

TREATMENT OF THE FRACTURE

Fractures of the vertebral column may be divided into those that involve primarily the anterior segment or those that involve the posterior segment Anterior

TABLE 3 —SUMMARY OF CORD BLADDERS
Cystometric data obtained from twenty four patients with spinal cord injuries

Cystometric criteria	*Cystometric data*			*Normal cord bladder*		
	Atonic cord bladder	*Autonomous cord bladder*	*Hypertonic cord bladder*	*Transected spinal cord*	*Other cord injuries*	*Normal bladder*
Initial tonus in cm						
High	8½	11	53	19	12	8
Average	1¾	5⅔	16	7	3¾	2½
Low	0	0	3	1	0	0
Average change in tonus with fill						
400 cc and over	+6¾	+9⅔	+23½	−1 85	+1 04	+3 54
300 cc and over	+5¾	+8¼		−1 96		+3 40
Over 0			+16	−2 09	+1 5	
To first contraction				−2 5	−0 5	+3 18
Emptying contractions						
Present	0	14	26	24	29	14
Absent	9	3	0	0	0	16
Capacity for storage in cu cm						
Over 400 cc	5	7	6	0	1	11
300–400 cc	4	6	7	0	1	7
200–300 cc	0	1	7	1	11	4
100–200 cc	0	2	4	8	7	3
50–100 cc	0	0	0	9	8	3
0–50 cc	0	1	8	6	1	3
Average amount of residual urine						
Per cent of fill	83 5%	42 6%	19 5%	5 97%	16 2%	0%
Anal and bulbo cavernosus reflexes						
Present	0	*	*	*	29	30
Absent	9	*	*	*	0	0
Resistance to catheter						
Present	0	0	0	0	29	30
Absent	9	17	26	24	0	0

* Insufficient data

SOURCE Munro D The cord bladder Its definition treatment and prognosis when associated with spinal cord injuries *J Urol* 36 710 1936

segment fractures are exclusively fractures of the vertebral body, while posterior segment fractures may involve either the neural arch (pedicles laminae articular facets and spinous processes) or the transverse processes

FRACTURES OF THE ANTERIOR SEGMENT

The majority of fractures of the vertebral body are due to flexion (jackknife) injuries in which the anterior wall is directly compressed mechanically, leading to a wedge shaped collapse of the body Others may involve principally the central portion of the vertebral body leaving the anterior wall relatively unchanged Frac-

tures of the posterior wall are less common and result from tension on the posterior longitudinal ligaments during the act of flexion

Flexion injuries of the cervical spine involve primarily the bodies of the lower cervical vertebrae (Fig 112) In the upper portion of the cervical spine it is *principally the odontoid process that is fractured By far the greater percentage of* fractures in the cervical spine are fracture dislocations, a combination form involving compression of the anterior segment with dislocation of the overlying vertebra (Figs 113 and 114) The upper vertebral body is displaced anteriorly, leading to the danger of compression of the cervical spinal cord at the upper border

FIG 112 Compression fracture of the cervical spine The body of the fifth cervical vertebra has been compressed with a loss of the normal cervical lordosis

of the undisplaced vertebral body immediately below the site of the dislocation In a high percentage of these cases the immediate outcome is fatal because of medullary compression In those in which death does not supervene laminectomy does not seem to have improved the outlook sufficiently and does not seem to warrant the risk that the additional trauma of operation imposes In these cases as well as *in those in which there is evidence of spinal cord involvement traction in extension* is the treatment of choice Extension however should not be attempted until the dislocation has been reduced

For purposes of temporary immobilization of the cervical spine a Sayre halter may be employed to exert traction in the longitudinal direction of the cervical

FIG 113 Fracture dislocation of the cervical spine There is a compression fracture of C4 with forward displacement of C3 and a fracture of the pedicle and the tip of the spinous process of C5

FIG 114 Fracture dislocation of the cervical spine There is compression fracture of the body of C5 with forward dislocation of C4

spine (Fig 115) Patients, however will not tolerate this form of traction for any prolonged period of time and skeletal traction must be used Two forms of skeletal traction have been devised by Barton and by Crutchfield In Barton s traction the tongs through which the traction is exerted are inserted into the skull just above the pinna of the ears (Fig 116) In Crutchfield s method, the tongs are inserted nearer the mid line in the parietal bones (Fig 117)

The insertion of the tongs is performed under aseptic precautions and the area into which the tongs are to be placed is carefully shaved and the mid line of the skull is marked on the skin A transverse line in the plane of both mastoid processes is then marked on the skin At the point where the transverse and longitudinal lines cross the mid point of the traction bar of the tongs is laid against the skin, so that it lies symmetrically in the plane of the transverse intermastoid line Where the tips of the tongs touch the skin, two small incisions are made under local

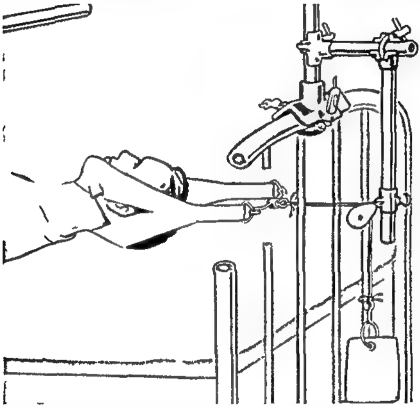


FIG 115 Sayre halter for cervical spine traction A halter or split linen bandage with chin and occipital pads are attached to weights over the head of the bed so as to make traction in the line of the axis of the cervical spine Hyperextension may be achieved by placing a pillow beneath the patient's shoulders (Courtesy of Gilbert Hyde Chick Company)

anesthesia, exposing the outer table of the calvarium Using a hand drill, the end of which is mechanically guarded so as to prevent penetration beyond 4 mm two small holes are drilled into the outer table of the skull The points of the tongs are inserted and the screw on the crossbar is tightened so as to fix the position of the tong points

Weights are attached to the traction bar and suspended over a pulley at the head of the bed For fractures or fracture dislocations involving the first cervical vertebra weights of no more than ten pounds are needed For fractures or fracture-dislocations of the lower most cervical vertebrae the weight may have to be increased

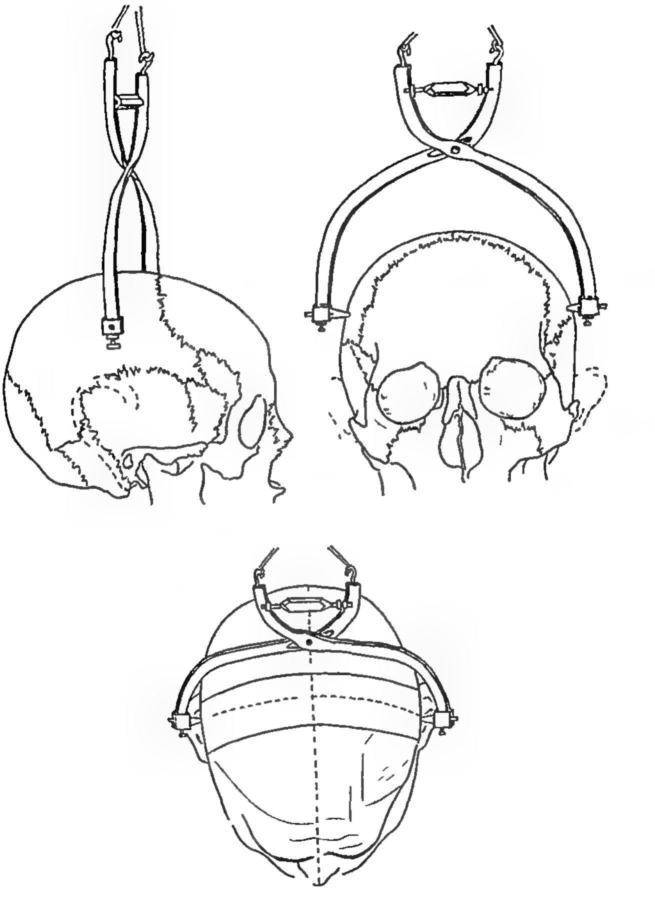


FIG 116 Barton's traction The tongs are inserted at a point about one inch above the pinnae of the ears in the intermastoid line

The insertion of the tongs is performed under aseptic precautions and the area into which the tongs are to be placed is carefully shaved and the mid line of the skull is marked on the skin A transverse line in the plane of both mastoid processes is then marked on the skin At the point where the transverse and longitudinal lines cross the mid point of the traction bar of the tongs is laid against the skin so that it lies symmetrically in the plane of the transverse intermastoid line Where the tips of the tongs touch the skin, two small incisions are made under local

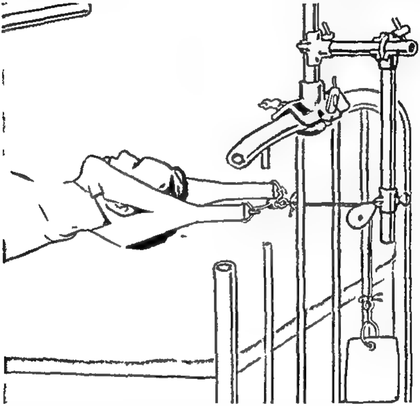


FIG 115 Sayre halter for cervical spine traction A halter or split linen bandage with chin and occipital pads are attached to weights over the head of the bed so as to make traction in the line of the axis of the cervical spine Hyperextension may be achieved by placing a pillow beneath the patient's shoulders (Courtesy of Gilbert Hyde Chick Company)

anesthesia exposing the outer table of the calvarium Using a hand drill the end of which is mechanically guarded so as to prevent penetration beyond 4 mm two small holes are drilled into the outer table of the skull The points of the tongs are inserted and the screw on the crossbar is tightened so as to fix the position of the tong points

Weights are attached to the traction bar and suspended over a pulley at the head of the bed For fractures or fracture-dislocations involving the first cervical vertebra weights of no more than ten pounds are needed For fractures or fracture-dislocations of the lower most cervical vertebrae the weight may have to be increased

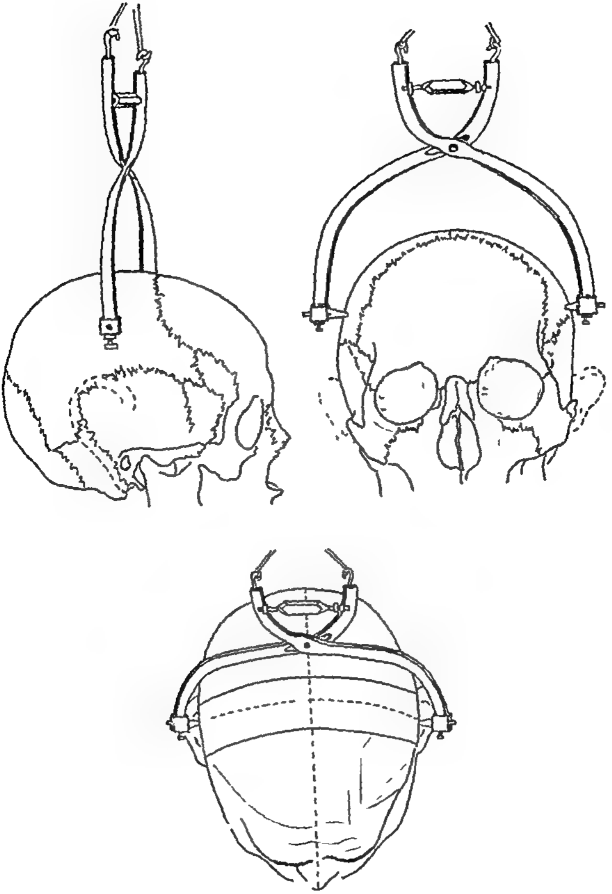


FIG 116 Barton's traction The tongs are inserted at a point about one inch above the pinnae of the ears in the intermastoid line

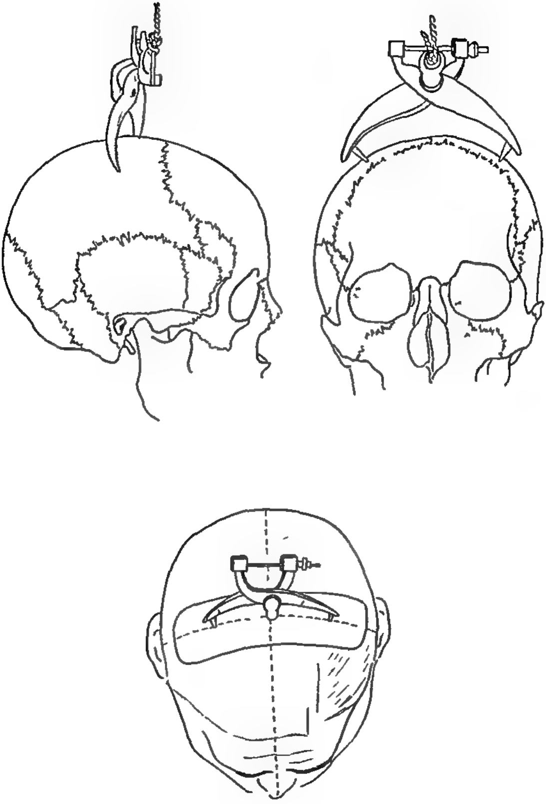


FIG 117 Crutchfield's traction The tongs are inserted nearer the vertex of the skull than in Barton's traction The exact site of insertion of the traction tongs is equidistant from the point of juncture of the mid line sagittal plane and the inter mastoid line

to as much as twenty five or thirty pounds This traction should be maintained only until x ray examination discloses reduction of the malalignment Thereafter, the traction may be reduced to the minimum amount, three to seven pounds necessary to maintain position For fractures of the lower vertebrae, traction over a period of about six weeks is usually sufficient to assure fixation of the fragment For fractures of the upper vertebrae, traction must be prolonged over a period of at least twelve weeks

At the end of this time the patient should be fitted with a cervical brace and a chin platform for a period of about six months (Fig 118) The patient should wear this brace at all times even when asleep

Where hospitalization for the period of time necessary for healing is impossible or undesirable a Minerva jacket should be applied This plaster jacket should be

FIG 118 Cervical spine brace The brace is supported on the shoulders has platforms for support of the chin and the occipital region and is fitted with extension screws so that traction may be maintained

applied while traction is maintained (Fig 119) It should be worn for a minimum period of about three months after which a platform brace or a Thomas collar should be used provided there is some evidence of healing (Fig 120)

Fracture of the odontoid process of the second cervical vertebra is particularly alarming because of the danger of injury to the medulla In large degree the liability to injury of the medulla depends upon the integrity of the orbicular ligament by which the odontoid process is fixed to the body of the atlas If at the time of injury this ligament is ruptured so that the tip of the odontoid process may be driven into the medulla, a quadriplegia and death are the outcome If, on the other hand the orbicular ligament is uninjured the prognosis in fractures of the odontoid process will depend to a large degree upon whether there is a simple fracture without dislocation of the body of the second cervical vertebra or whether the dislocation is of primary importance

Cases of simple fracture without dislocation are of relatively little significance These patients frequently walk into the clinic and the diagnosis is established only after careful roentgenographic examination These patients usually will not tolerate

hospitalization and need not be put into traction They should be immobilized in a Minerva jacket that should extend from the occiput to the upper part of the thorax and should be worn for a period of at least six months (Fig 121) Thereafter, a Thomas collar should be worn for an additional period of three to four

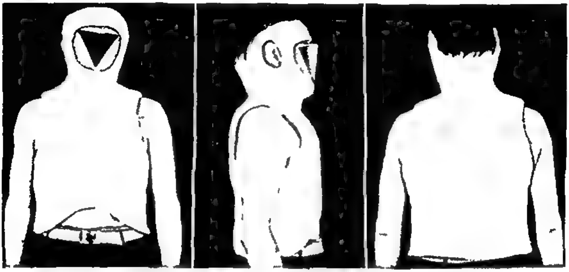


FIG 119 Minerva jacket The cast extends from the iliac crest to the occipital region and includes the chin A plaster fillet serves to immobilize the head (See also Fig 96)

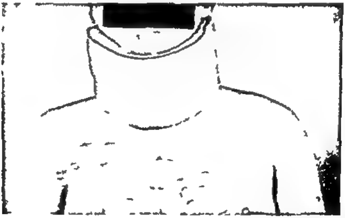


FIG 120 Thomas collar After removal of a Minerva jacket immobilization of the neck may be continued by means of a reinforced sponge rubber or heavy felt Thomas collar

months or until there is roentgenographic evidence of bone union Bony union usually takes place but nonunion or fibrous union may occur Even nonunion need not necessarily cause the patient any distress Cases are on record where congenital nonunion of the odontoid process has been observed without any disability to the patient or any impairment of function

Cases in which fracture of the odontoid process are associated with dislocation of the body of the second cervical vertebra fall into an entirely different category In such instances, as a result of the forward displacement of the atlas (C1), either the anterior surface of the cord is crushed against the upper border of the axis (C2) or the posterior surface of the cord is crushed by the advancing lower border of the atlas This results in the appearance of spinal cord symptoms that will vary from pure motor paralysis resulting from involvement of the pyramidal tracts to sensory

FIG 121 Fracture of the odontoid process This fracture cannot be readily visualized except on an anteroposterior view taken through the open mouth The base of the process is fractured and displaced slightly upward but there is no tilting of the fragment suggestive of rupture of the orbicular ligament

disturbances in the occipital region and the upper extremity and death caused by compression of the medulla

The indication for treatment is not primarily the fracture, but rather the reduction and maintenance of the dislocated segment As in other fracture-dislocations of the cervical spine longitudinal traction, preferably by means of Crutchfield tongs, is essential This must be continued until there is evidence of realignment of the cervical column Excessive weight with distraction of the segments should be avoided by careful routine and frequent x ray examination If after several weeks bed rest with traction there is evidence of satisfactory alignment, traction may be discontinued and substituted by plaster immobilization that should be applied with the patient supine while in traction The plaster cast should be worn until there is x ray evidence of healing usually in four to six months Thereafter the patient should be advised to wear a Thomas collar for several additional months

A marked tendency toward recurrence of dislocation has been noted in these cases and some surgeons have therefore advised routine fusion of the atlantoaxial joint

hospitalization and need not be put into traction They should be immobilized in a Minerva jacket that should extend from the occiput to the upper part of the thorax and should be worn for a period of at least six months (Fig 121) Thereafter, a Thomas collar should be worn for an additional period of three to four

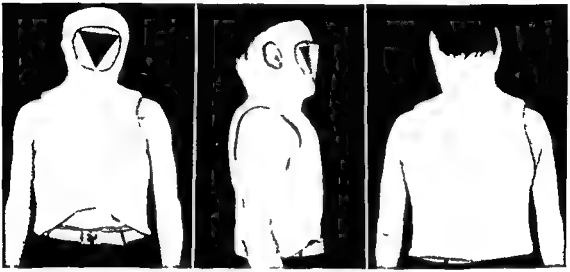


Fig 119 Minerva jacket The cast extends from the iliac crest to the occipital region and includes the chin A plaster fillet serves to immobilize the head (See also Fig 96)

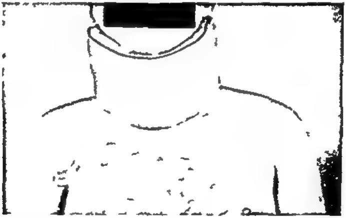


Fig 120 Thomas collar After removal of a Minerva jacket immobilization of the neck may be continued by means of a reinforced sponge rubber or heavy felt Thomas collar

months or until there is roentgenographic evidence of bone union Bony union usually takes place but nonunion or fibrous union may occur Even nonunion need not necessarily cause the patient any distress Cases are on record where congenital nonunion of the odontoid process has been observed without any disability to the patient or any impairment of function

FIG 123 Compression fracture of the thoracic spine There is triangulation of the body and a free fragment at the anterosuperior border of the eleventh vertebra Calcification of the anterior vertebral ligament between the bodies of T11 and T12 and between T12 and L1 is seen

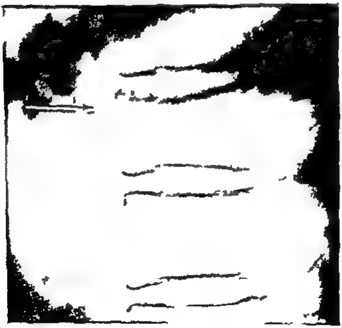


FIG 124 Compression of the thoracic spine There is slight triangulation of the body with a fracture of the anterosuperior portion of T9 Calcification in the anterior vertebral ligament is seen immediately subjacent to the level of the fracture

WHIPLASH INJURIES

Whiplash injuries of the cervical spine have become an increasingly common type of injury as a result of rear-end automobile collisions Small fractures of various parts of the vertebrae have been described as a consequence of the sudden enforced flexion and extension of the neck More frequently, however, the injuries involve the soft tissues such as the intervertebral discs, the ligamentous structures or the nerves of the neck They are frequently disabling and may require immobilization by means of a Thomas collar or a platform brace until symptoms have disappeared

FRACTURES OF THE THORACIC SPINE

Fractures of the vertebral bodies in the thoracic spine occur most commonly at the junction between the normal thoracic kyphosis and the lumbar lordosis i e at the level of the twelfth thoracic and the first lumbar vertebrae (Fig 122) They

FIG 122 Compression fracture of the thoracic spine The body of the twelfth thoracic vertebra is compressed and triangulated Healing has occurred in this position

may however involve the bodies of vertebrae higher in the vertebral column (Figs 123 and 124) Most frequently they are simple compression type of flexion fractures with wedging of the vertebral bodies They may also be of the central or stellate types and may be comminuted One or more bodies may be fractured and the injury may be associated with prolapse of the intervertebral disc leading to compression of the cord or the nerve roots Immediately after the injury the patient usually complains of pain that should never be dismissed casually as a sprain In many instances these fractures may pass unnoticed and be discovered years later during the course of a subsequent routine examination Treatment in the acute case

FIG 123 Compression fracture of the thoracic spine There is triangulation of the body and a free fragment at the anterosuperior border of the eleventh vertebra Calcification of the anterior vertebral ligament between the bodies of T11 and T12 and between T12 and L1 is seen

FIG 124 Compression of the thoracic spine There is slight triangulation of the body with a fracture of the anterosuperior portion of T9 Calcification in the anterior vertebral ligament is seen immediately subjacent to the level of the fracture

should be directed toward restoration of the normal anatomical configuration of the vertebral body While it is true that even marked wedging may result in few or no symptoms, even slight malalignment may lead to persistent pain in the back The treatment of these compressed fractures is by hyperextension

Hyperextension may be brought about in a number of different ways The patient may be placed supine in bed with a pillow at the level of the fracture site The

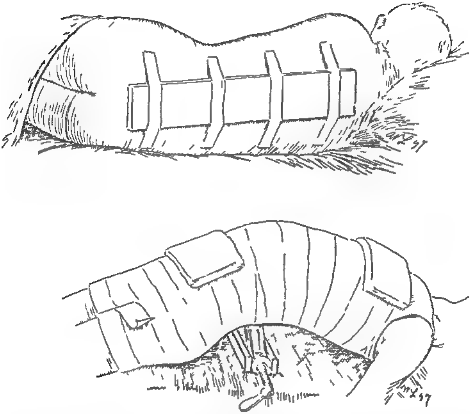


FIG 125 Application of hyperextension body jacket A felt pad is fixed to the back over the vertebral column Heavy felt pads are placed over the pubis and clavicles and the patient is hyperextended over an automobile jack or suitable hyperextension frame Plaster of Paris extending from the region of the clavicles to the pubis is applied As soon as the plaster has set the apparatus is removed and the cast is completed

patient may be suspended in the prone position between two tables with the chest resting on one table and the pelvis on the other The lower extremities may be suspended while the chest rests upon a support or the patient's spine may be hyper extended by means of an ordinary automobile jack or by rest on a Goldthwait or Herzmark frame Once the normal alignment has been restored as determined by x-ray examination the patient's trunk may be immobilized in a plaster of Paris body cast extending from the pelvis at least to the manubriosternal angle of Louis (Fig 125) The jacket should be worn for a minimum period of twelve weeks dur

ing which time the patient may be ambulatory Thereafter a Taylor two-bar brace with shoulder straps should be used to maintain the position of hyperextension

Fractures of the body of the upper thoracic vertebrae present a special problem since hyperextension is not normally possible in this region Neither brace nor

FIG 126 Compression fracture of the lumbar spine There is triangulation of the body of the first lumbar vertebra and a central fracture of the body of the fourth lumbar vertebra

plaster treatment is of much value in such instances If symptoms persist fusion of the involved vertebrae may be justified Otherwise symptomatic therapy alone is indicated

Where the central portion of the body is compressed and the anterior wall is but little collapsed hyperextension which exerts its influence through the anterior longitudinal ligament is of practically no value Patients with such fractures should

be treated symptomatically and usually manifest but little disability If symptoms persist operative fusion with the adjoining vertebrae is indicated

Excessive hyperextension is to be avoided, since overcorrection leads to separation of the fragments and may lead to bowel or bladder symptoms owing to traction on the spinal cord Under such circumstances the hyperextension must be immediately reduced and plaster of Paris cast application should be delayed until all symptoms of the complication have subsided

While this is the accepted method of treatment for compression fractures of the vertebral bodies, some surgeons of the English school have claimed that their end results, as regards the patient s ability to resume his normal occupation were much better when the patients were treated without any sort of immobilization The patients are kept at complete bed rest during the acute phase and are encouraged in

FIG 127 Compression fracture of the lumbar vertebra There is a fracture of the anterosuperior portion of the body of the fourth lumbar vertebra

the performance of exercises designed to strengthen the back muscles as soon as the acute pain has subsided They have noted that in a very high percentage of the cases reduced in hyperextension the appearance of compression recurred during aftertreatment They note further that there is little relationship between the roentgenographic appearance of the vertebral body and the patient s ability to resume his normal work That this may be the case in uncomplicated stable fractures of the vertebral body has already been indicated by the fact that in many cases *triangulated* vertebrae the result of antecedent fractures have been found accidentally without ever having caused the patient any known symptomatology

Fracture dislocations of the thoracic spine a combination form of anterior and posterior segment fracture are usually not amenable to hyperextension treatment Where alignment is not possible by traction and hyperextension some have advised operative reduction with immediate fusion of the involved vertebrae

Fractures of the lumbar spine essentially resemble those of the thoracic spine and the treatment is the same Compression fractures of the anterior segment occur more commonly at the level of the first and second lumbar vertebrae (Figs 126 and 127)

Fractures of the Posterior Segment

Fractures of the posterior segment include fractures of the transverse process and fractures of the neural arch, which encompass fractures of the pedicles, laminae, articular processes, and spinous processes As a general rule, neurological compli-

Fig 128 Clay shoveler's fracture There is a fracture of the tip of the spinous process of the first thoracic vertebra

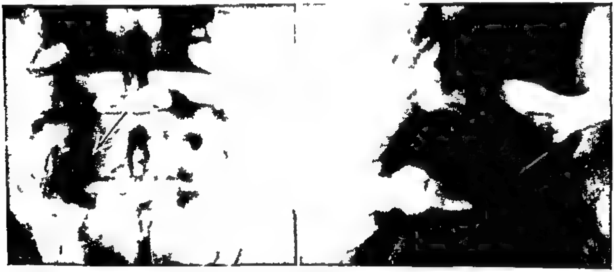


Fig 129 Facet fracture of the lumbar vertebra The inferior articular facet of L5 on the right side is fractured There is but little separation of the fragments (*Left*) Anteroposterior view (*Right*) Oblique view

cations of spine fractures are more common in fractures of the neural arch than in those of the body

In the lower cervical region a special type of fracture of the spinous process, described as *clay-shoveler's fracture* is not uncommon This involves the spinous process of the seventh cervical or the first thoracic vertebra and is usually an avulsion fracture occurring at the site of attachment of the ligamentum nuchae and the rhomboid muscles (Fig 128) Although they may occur as a result of direct vio-

lence, they are usually found in laborers and occur during the act of motion involved in pitching material into the air The condition is painful but not dangerous In some instances, cure has resulted from purely conservative methods If pain is not excessive, no treatment or at most immobilization in a cervical collar is sufficient If symptoms persist, however, removal of the fragment usually gives relief Nonunion is not infrequent and the disability may last for a considerable period of time

FIG 130 Neural arch fracture of the lumbar spine There is a fracture of the spinous process of L4 and L5 (Reproduced from Milch H Whip lash injury of the lumbar neural arch *Bull Hosp Joint Dis 15* 163 1954)

Fracture dislocations of the cervical spine usually involve fracture of the pedicle or lamina of the involved vertebra (Fig 113) Treatment is usually accomplished by traction in the line of the vertebral column until reduction is complete after which gentle hyperextension of the neck may be made Immobilization should be continued either by traction or by application of a plaster of Paris Minerva jacket for an additional period of two to four months

Fractures of the neural arch in the thoracic region are most frequently the result of direct blows and are most likely to lead in depressed fractures with injury to the cord Where there is no cord injury, traction in the straight line of the body is indicated Attempts at hyperextension are usually unavailing and may serve to depress a fragment of the fractured posterior segment and thus lead to injury of the under-

lying cord Where there is evidence of cord injury and x-ray evidence of depressed fracture, immediate laminectomy is indicated

In the lumbar region, *fractures of the facet* give rise to a special type of low-back syndrome, which has been designated as the facet syndrome (Fig 129) It is characterized by disability, limitation of motion in the lumbar spine, and localized pain occasionally radiating along the distribution of the sciatic nerve In the acute stage, immobilization in a plaster of Paris cast is indicated In the chronic stage, where pain and nonunion persist, fusion of the involved and adjacent vertebrae will relieve the symptoms

FIG 131 Fracture of the transverse processes There are fractures of the transverse processes of the second third and fourth lumbar vertebrae on the right side Bony union has occurred

Fracture of the spinous process is more common than is usually recognized (Fig 130) Particularly in the lower lumbar vertebrae, it may be difficult to diagnose these conditions even on carefully made radiographs In such instances, a variation in the angle formed between the superior surface of the body of the vertebrae and the superior border of the spinous process greater than thirty degrees is extremely suggestive of a malalignment owing to a loss of continuity in the neural arch This may be due to a congenital or traumatic spondylolisthesis or to a fracture of the body or of the neural arch Treatment is by means of immobilization in a plaster of Paris jacket and, if symptoms persist, by operative fusion of the involved vertebrae

Fractures of the transverse processes of the lumbar vertebrae probably result from muscular avulsions or from a combination of direct trauma and muscular avulsion Usually considered to be of trivial consequence, these fractures are more dis-

abling than is generally admitted In addition to the bony fracture, there is invariably extensive laceration of the muscle and soft tissues about the fracture and disability may be considerably prolonged These patients are frequently unjustifiably accused of malingering Where there is simple fissuring of the bones without any separation of the fragments, strapping of the back or a firm corset support is usually sufficient to assure subsidence of the symptoms Where there is definite separation of the fragments immobilization by means of a plaster of Paris jacket is imperative Union may be fibrous or bony if separation is minimal (Fig 131) The appearance of nonunion and the persistence of symptoms is no indication for the removal of the fractured fragment The symptoms are usually due to scar formation in the soft tissues, which will not be improved by extirpation of the fragment

CHAPTER 11

Fractures of the Thoracic Cage

Fractures of the thoracic cage include fractures of the ribs and of the sternum Although theoretically the thoracic spine may be included as part of the thoracic cage, fractures in this region are more properly considered under fractures of the vertebral column

Fractures of the Ribs

Because of their inherent elasticity, ribs are only occasionally fractured in children When such fractures do occur they are usually the result of severe crushing injuries, in which the general condition of the child is more important than the treatment of the fracture itself As a result of a direct blow individual ribs may be fractured, but these are seldom complete and seldom involve the underlying parenchymal structures Immobilization of such fractures is possible either by adhesive strapping of the hemithorax involved or by completely swathing the chest in an encircling muslin bandage While the muslin bandage avoids the likelihood of injury to the underlying skin, it is more difficult to maintain in place than adhesive strapping Immobilization seldom has to be maintained for more than two to three weeks

In adults, fractures involving the third to the ninth ribs are most common and are frequently multiple The first and second ribs are protected from direct violence by the overlying clavicle, but may be fractured as the result of sudden, severe muscular action as in coughing or sneezing The lower floating ribs are infrequently fractured because of their mobility Fractures of the intervening ribs may occur at any point in their course Anteroposterior compressive forces tend to cause an outward buckling of the fracture ends and seldom cause injury of the underlying pleura or lung Lateral compressing forces, on the other hand, tend to cause an inward buckling of the convex rib and are more frequently associated with injury to the underlying structures (Fig 132)

Rib fractures may be multiple or may occur at several different sites in the same rib (Fig 133) Depending upon the severity of the injury, displacement may be minimal or may present overriding Where several ribs are involved, flattening of

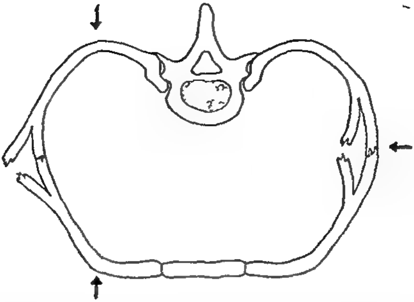


FIG 132 Rib fractures Anteroposterior compressive forces tend to lead to rib fractures with outward angulation Lateral compressive forces tend to lead to inward angulation at the site of fracture with attendant danger of intrathoracic injury

FIG 133 Multiple rib fractures As a result of anteroposterior compression there are fractures of the third to eighth ribs on the right side with outward angulation at the site of fracture There was no involvement of the underlying lung

the chest wall frequently occurs Where fracture of multiple ribs is combined with multiple fractures within the ribs, staving in of the chest wall occurs This may be associated with *paradoxical respiration* (on inspiration, the involved segment of the chest wall is drawn inward, while, on expiration, it moves outward) This is a serious complication in that ventilation of the involved lung is impaired The only treatment is by firm immobilization either by weights or by a tight compressive dressing

Compound fractures resulting from penetrating or perforating injuries are fairly rare save under war conditions The problem in these cases is not primarily that of the fracture, but rather that of the treatment of a contaminated wound of the thorax and possible disturbance in cardiorespiratory physiology Its treatment falls within the domain of the thoracic surgeon

Simple fractures of the ribs can readily be diagnosed clinically and roentgenographically in most cases (Fig 134) Treatment is directed toward control of pain that is accentuated by respiratory motion Immobilization has been carried out most

FIG 134 Isolated rib fracture There is a fracture of the fourth rib at the junction of the head and neck with only slight displacement at the site of fracture

commonly by strapping of the chest Some advocate strapping at the end of inspiration others at the end of expiration The latter is preferable since it affords firmer fixation of the fractured fragments Strapping may be applied with the patient either in the seated or standing positions and with the arms elevated In general the adhesive tape straps should be applied obliquely from above and behind to below and in front following the generally oblique course of the ribs, and should extend slightly beyond the mid line both anteriorly and posteriorly (Fig 135) Complete encirclement of the chest should be avoided as tending to interfere too greatly with respiration The nipples should be protected by a small dressing If the upper ribs are involved, longitudinal strapping over the top of the shoulder may be applied to secure additional immobilization In women the presence of the breast

prevents adequate strapping of any but the lower ribs For fractures of the upper ribs, firm bandaging of the chest with adequate protection of the breast is all that can be accomplished

Strapping that has become loose should not be removed since the skin is further traumatized The dressing may be reinforced by additional adhesive straps applied over the original strapping After two to three weeks, sufficient fibrous callus will usually have formed between the fractured bone ends to render additional strapping unnecessary

If possible, strapping should be avoided, since it markedly reduces respiratory capacity and may lead to pulmonary complications Since the primary function of immobilization is the control of pain, it may be avoided if regional injections of local anesthetics, repeated as indicated, can be made directly into and about the site of fracture Unless the general condition of the patient contraindicates it, ambulation is to be preferred to bed rest

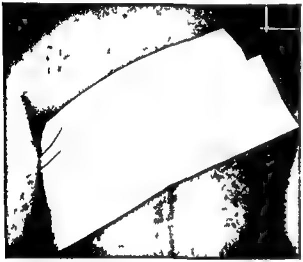


Fig 135 Strapping of the chest Three inch adhesive tape strips are applied obliquely along the course of the ribs and extend beyond the mid line both anteriorly and posteriorly

Fractures of the Sternum

Fractures of the sternum are exceedingly rare injuries and usually result from direct blows or severe compressive injuries The fracture usually occurs through the angle of Louis at the junction of the manubrium and body of the sternum When *the injury results from direct blow as in automobile accidents where the steering* wheel strikes the chest, the distal fragment is displaced backward (Fig 136) In hyperflexion injuries, such as may occur from fracture of the upper thoracic vertebrae, the lower fragment may be displaced anteriorly The diagnosis in the presence of displacement can be made only on lateral roentgenograms of the sternum Where there is no displacement simple bed rest is sufficient (Fig 137) Even in cases of displacement, treatment may not be indicated, since the fractures invariably heal with but slight deformity and usually with no functional impairment To correct a deformity treatment will vary with the direction of the displacement In anterior displacement of the body of the sternum hyperextension of the thoracic spine ac-

FIG 136 Fracture of the sternum There is posterior displacement of the gladiolus with separation at the angle of Louis Marked respiratory embarrassment was promptly relieved by anterior transposition of the displaced distal fragment

FIG 137 Fracture of the sternum There is a separation between the manubrium and gladiolus without displacement of the fragments There is an oblique fracture of the posterior surface of the manubrium without apparent displacement immediately above the superior border of the shadow of the fourth rib

companied by manual depression of the fragment under local anesthesia frequently gives satisfactory results

Where the displacement of the body is posterior, respiration may be embarrassed and reduction may be necessary Skeletal fixation by means of a towel clip inserted through the skin into the cancellous bone of the body and balanced traction frequently serve to overcome the displacement (Fig 138) If neither of these

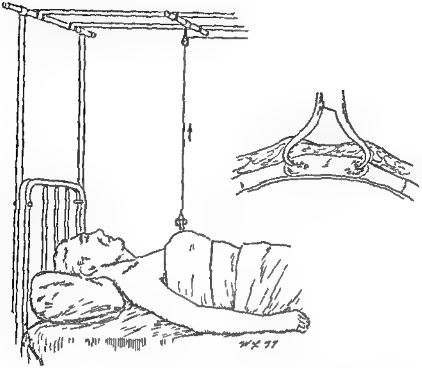


FIG 138 Balanced traction for fracture of the sternum The posteriorly displaced fragment may be transfixed by a towel clip to which weights suspended from a Balkan frame may be attached (Reproduced from Cameron D A Injuries to the thorax, *Mod Med 20* 116 1952)

methods succeeds open operation with gentle levering of the fragments into place is usually successful The reduced position may be maintained by free grafts of fascia lata, sutures, or small straight Lane-type plates In most instances union is sufficiently satisfactory at the end of three weeks to permit ambulation of the patient

Fractures of the xiphoid process are extraordinarily rare Posterior displacement of the process may occasionally give rise to abdominal symptoms in which event the process may be excised

SECTION III

The Appendicular Skeleton Upper Extremity

CHAPTER 12

Fractures of the Pectoral Girdle

Fractures of the pectoral girdle include fractures of the scapula and of the clavicle

Fractures of the Scapula

Fractures of the scapula may affect the body of the bone or any of its processes, the acromion, the scapular spine, the coracoid process, or the glenoid

Fractures of the body are usually the result of direct blows over the bone Because of its coverage by the subscapularis, the infraspinatus, and the supraspinatus muscles, there is little tendency for marked displacement of the fragments The fracture lines may be linear or stellate and, though they usually are situated within the body of the bone, may extend to the vertebral and axillary borders Roentgenographic diagnosis is frequently difficult and may be confused with fractures of the underlying ribs, which are not infrequently associated with fractures of the body of the scapula If the fascial covering is not torn, the large hematoma localized to the area of the scapula is the most important clinical finding Motion of the arm is frequently inhibited because of pain

Treatment is primarily directed toward limitation of motion to prevent pain This may be achieved by simple adhesive tape dressing that is applied from both clavicles posteriorly across the injured scapula to opposite sides of the chest (Fig 139) It is desirable to immobilize the arm at the side of the chest, since pain is elicited when the scapula is fixed by contraction of the periarticular muscles that is necessary in order to permit motion of the humerus Immobilization of the shoulder should, however, not be continued beyond the period necessary to control pain so as to obviate the development of periarthritic stiffening of the shoulder

Fracture of the acromion process is rare, and occurs as a result of direct violence The fracture line may pass through the base of the acromion (Fig 140) rarely through the outer portion of the process or lateral to the acromioclavicular joint In the former instance, under the influence of the weight of the arm, the fragment tends to be displaced downward with the shoulder When the fracture line occurs lateral to the acromioclavicular joint, there is little tendency toward displace-

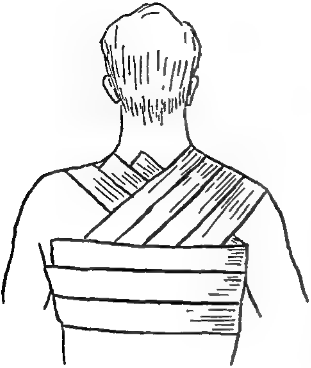


FIG 139 Immobilization of fracture of the body of the scapula Adhesive strips from both clavicular regions cross the involved scapula posteriorly and are anchored on the anterolateral aspects of the chest wall The dressing is reinforced by transverse strips that encircle the hemithorax on the affected side (Reproduced from Milch H Fractures of the shoulder girdle *Mod Med 18* 47, 1950)

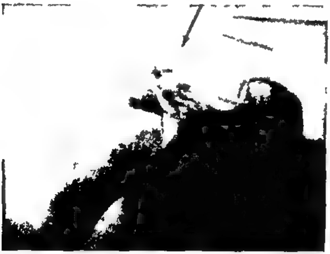


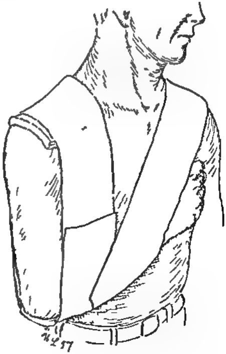
FIG 140 Fracture of the acromion process A fracture has occurred at the junction of the base of the acromion with the spine of the scapula There is a slight tendency toward downward displacement of the fragment

ment Simple immobilization of the arm at the side by a Velpeau dressing is usually sufficient (Fig 141)

When there is displacement as a result of fracture through the base of the acromion, treatment consists of elevation of the shoulder by adhesive strapping as in the treatment of acromioclavicular dislocations The outer end of the clavicle is padded with a strip of felt and adhesive strapping is placed about the flexed elbow

FIG 141 Velpeau dressing The arm is immobilized against the trunk by bandage or adhesive strips encircling the arm and the trunk A pad should be placed in the axilla and in the antecubital fossa and a small dressing should be placed betwen the flexed forearm and the chest wall In fractures of the acromion or clavicle the extremity may be elevated by adhesive strips encircling the flexed elbow and running over the shoulder

FIG 142 Immobilization of fractured acromion To overcome the downward displacement of the fractured acromion a felt pad is placed over the outer end of the clavicle The arm is pushed upward by an adhesive tape strip that encircles the elbow and is fixed over the pad at the outer end of the clavicle A few transverse strips of adhesive convert this dressing into a Velpeau type of immobilizing dressing



so as to force the shoulder upward toward the fractured base It is anchored in place over the pad on the outer end of the clavicle The shoulder should be fixed to the side by an adhesive tape strip encircling the chest and the humerus The forearm should be supported by a sling around the neck and the entire arm should be supported in a Velpeau dressing to maintain the upward position of the fractured fragment (Fig 142) If the displacement cannot be overcome and interferes with later

FIG 143 Gunshot fracture of the spinous process of the scapula There is a comminuted fracture of the spinous process that healed satisfactorily under simple immobilization

abduction of the arm that portion of the acromion lateral to the acromioclavicular joint may be resected

Fracture of the spinous process is usually the result of direct injuries (Fig 143) There is usually little displacement and the main indication is for immobilization of the scapula as in fractures of the body, until such time as the pain has subsided

Isolated fracture of the *coracoid process* is rare and may result from avulsion by the muscles that are attached to it (Fig 144) In such event, the fragment is usually displaced downward In order to relax these muscles, treatment by placing the hand upon the opposite shoulder has been recommended This seldom results in restitution of the fragment and union is usually of a fibrous nature This does not appear, however, to affect the use of the arm After about three weeks of immobilization, normal use of the arm within the limits of pain should be encouraged More fre-

FIG 144 Epiphyseal separation of the coracoid process There is a fracture of the clavicle with an associated separation of the coracoid epiphysis This type of fracture must be carefully differentiated from the appearance of a normal epiphysis that occurs at this site

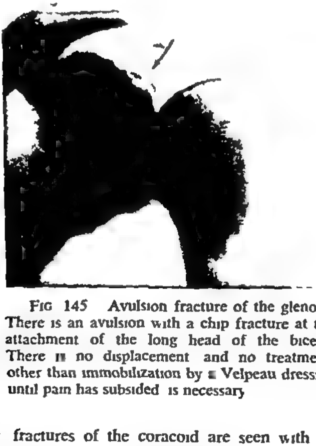


FIG 145 Avulsion fracture of the glenoid There is an avulsion with a chip fracture at the attachment of the long head of the biceps There is no displacement and no treatment other than immobilization by a Velpeau dressing until pain has subsided is necessary

quently, however fractures of the coracoid are seen with other injuries to the shoulder in which the treatment of the coracoid fracture becomes secondary in importance to the treatment of the associated injuries

Fractures of the glenoid occur as the result of falls on the arm Small chip fractures of the anterior or inferior margins are not uncommonly seen in dislocation of

FIG 146 Avulsion fracture of the glenoid There is a fracture of the inferior margin of the glenoid with recurrent dislocation of the shoulder Infraction of the humeral head characteristically seen in recurrent dislocations is well demonstrated Treatment in this case was the treatment of the recurrent dislocation by a Putti Platt procedure

FIG 147 Infraglenoid fracture of the scapula There is a fracture of the axillary border of the scapula below the glenoid cavity with downward and inward displacement of the upper fragment (*left*) Treatment consisted of traction with the arm in abduction with satisfactory outcome (*right*)

the shoulder and are reputed by some to be the cause of a tendency toward recurrent dislocations Avulsions of small portions of bone at the superior margin of the glenoid may result from the action of the biceps (Fig 145) Avulsion of a small portion of bone at the inferior margin of the glenoid may result from the action of the triceps muscle (Fig 146) In either case, the separation is minimal and immobilization of the arm at the side until pain has subsided is all that is necessary

Fractures of the neck of the glenoid or the infraglenoid portion of the axillary border may result in a downward and inward displacement of the plane of the glenoid cavity so as to impair abduction of the arm Where this occurs, replacement of the fractured fragment must be accomplished with the patient recumbent in bed and the arm in abduction If the glenoid cavity is involved and comminuted, traction on the abducted arm may serve to restore the alignment and, in any event, will tend to minimize the tendency toward stiffness of the shoulder (Fig 147)

Fractures of the Clavicle

The clavicle is one of the most commonly fractured bones in the body, especially in children In the great majority of cases, the fracture occurs at the junction of the middle and outer thirds of the bone and is the result of either a fall on the

Fig 148 Green stick fracture of the clavicle There is downward displacement of the outer end The apparent dissolution of continuity at the acromion process is the site of a normal epiphyseal growth line Treatment in this case was by simple upward displacement of the humerus forcing the clavicle into correct alignment

outstretched hand or a direct blow against the clavicle In children, the fracture is frequently incomplete and is characterized by an increased anterior bowing (Fig 148) In adults, the fracture is usually complete and is characterized by downward, forward, and inward displacement of the lateral fragment (Fig 149)

FIG 149 Fracture of the clavicle There is typical down ward and inward displacement of the outer end of the clavicle Realignment was attained by a simple figure of eight dressing

In children, where the green-stick fracture is not associated with marked anterior bowing, immobilization of the arm against the side of the thorax in an ordinary Velpeau dressing usually gives satisfactory results Where the bowing is more marked and unsightly, this should be corrected by pressure against the apex of the curve with subsequent immobilization of the clavicle in a figure-of eight dressing

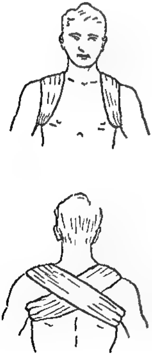


FIG 150 Figure of eight dressing for clavicular fractures The dressing is applied over both shoulders and crosses posteriorly It may be reinforced by a plaster of Paris bandage applied over the dressing or by a plaster of Paris yoke placed anteriorly between the outer ends of both clavicles (Reproduced from Milch H Fractures of the shoulder girdle, *Mod Med 18* 47 1950)

to maintain the length of the clavicle (Fig 150) Although desirable complete end to-end apposition of the fragments is not necessary This is especially true in children Provided that the alignment is satisfactory, the callus that forms and the subsequent remodeling of the bone will obliterate any trace of the deformity (Fig 151) In adults, however, more accurate reposition is desirable

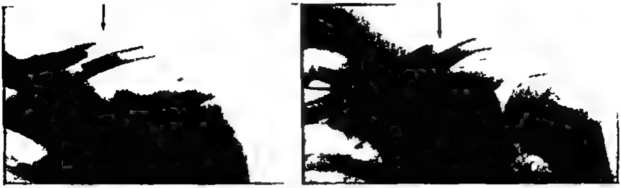


FIG 151 Fracture of the clavicle in a child There is a fracture of the outer third of the bone with overriding (*left*) Anatomical reposition was not accomplished, but alignment was satisfactory and the cortices of the bone were locked (*right*)

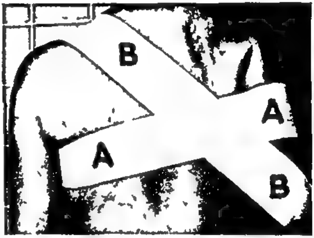


FIG 152 Sayre dressing A strip of adhesive is fastened loosely about the upper end of the humerus on the affected side and is passed posteriorly across the thorax while the arm is forced backward *A* The adhesive is then fixed to the anterior aspect of the opposite hemithorax A second strip of adhesive is then passed from the opposite shoulder to below the elbow on the affected side while the arm is pushed upward *B* This serves to elevate the depressed fragment Immobilization may be completed by a Velpeau dressing

Reduction is relatively simple, and can usually be obtained by pulling the lateral end of the clavicle outward and backward while pressure is made over the lower end of the humerus to force the fractured fragment upward Maintenance of the position frequently offers difficulty In children, a figure of-eight dressing over the points of both shoulders and crossing posteriorly is usually satisfactory This type of dressing may be reinforced by a plaster of Paris bandage applied over the figure-of-eight bandage and may be further reinforced by a plaster of Paris yoke applied anteriorly over the points of the shoulders to hold the shoulders backward The anterior plaster yoke has the advantage of obviating pressure on the brachial plexus, which the figure-of-eight bandage may exert

In adults a satisfactory form of reducing and holding a fracture of the clavicle is that described by Sayre (Fig 152) The Sayre dressing involves the application of a circular adhesive dressing around the humerus for the purpose of drawing the shoulder backward Once the shoulder is drawn sufficiently backward, the adhesive tape is wrapped about the chest of the opposite side Upward displacement of the fragment is accomplished by applying a long strip of adhesive tape to the forearm with the elbow flexed Pressure is then exerted on this strip to pull the shoulder

upward and the strip is then passed posteriorly and fastened across the top of the opposite shoulder If the reposition is satisfactory, the dressing is completed by a Velpeau bandage

Other methods of reducing and maintaining clavicle fractures include the clavicular cross or barrel staves made into the form of a cross and fixed posteriorly to the trunk The shoulders are then pulled backward against the crossarms and fixed

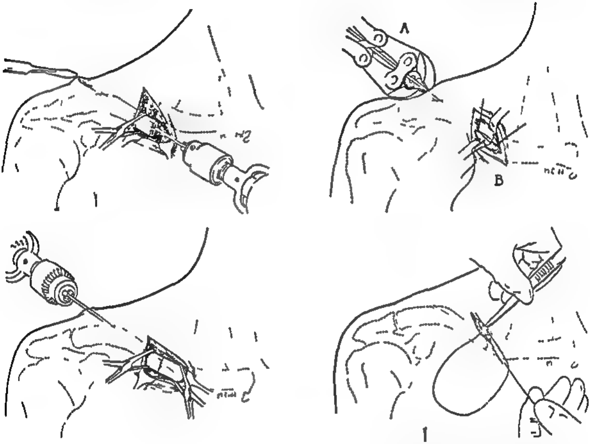


FIG 153 Intramedullary fixation of clavicular fractures A small skin incision is made directly over the fracture site and a Steinman nail is passed retrograde through the outer fragment The fracture is then reduced manually and the Steinman nail is driven into the medial fragment The excess nail is cut off and the skin wound closed (Reproduced from Quigley T B Management of simple fracture of the clavicle in adults *New England J Med* *243* 286 1950)

in place Where none of these methods is successful, satisfactory reduction can almost invariably be accomplished by recumbency in bed with a small pillow between the shoulder blades

Open operation and even intramedullary fixation have been described by many in the treatment of clavicular fractures This method however, should not be used routinely Where indicated intramedullary fixation may be accomplished by a firm steel rod or Steinman nail The site of the fracture is exposed through a small incision and the nail is driven retrograde into the lateral fragment until its point ex-

FIG 154 Intramedullary fixation of fractured clavicle Preoperatively there was marked downward and inward displacement of the left clavicle The existence of other fractures in the left upper extremity precluded closed reduction and intramedullary fixation was indicated The pin was left in situ even after healing was complete

tends to just beyond the site of the fracture and its distal end extends beyond the skin of the shoulder The fragments are then manually reduced and the intramedullary device is driven into the medial fragment a sufficient distance to immobilize the fractured ends firmly The portion of the pin that projects beyond the skin is cut so that the pin ultimately comes to lie beneath the skin The skin wound is then closed and the arm is immobilized in a figure-of eight, Velpeau, or Sayre dressing The pin may be left in situ or may be removed after union has been completed, usually within four to six weeks (Figs 153 and 154)

Fractures of the lateral or medial extremities of the clavicle are usually not associated with any marked displacement, because of the stabilizing action of the coraco-clavicular and rhomboid ligaments Treatment of these fractures involves simple immobilization until pain has subsided

CHAPTER 13

Fractures of the Humerus

Fractures of the humerus arise as a result of direct or indirect trauma Those that occur above a line extending approximately between the levels of insertion of the teres major and the pectoralis major muscles are considered as fractures of the upper end Those occurring below a line that lies slightly above the condylar prominences are considered as fractures of the lower end Between these upper and lower limits fractures are considered as being of the shaft

FRACTURES OF THE UPPER END

These include fractures of the head, the tuberosities, and the anatomical neck and surgical neck of the humerus They usually occur in varying degrees of abduction of the arm and result in correspondingly different types and extent of fractures

Fractures of the Head

Isolated fractures of the head are extremely rare and are probably best treated by traction under the molding influence of motion *Infractions of the humeral head* are, on the other hand rather common They usually occur in association with chronic dislocations of the shoulder and may be diagnosed roentgenographically as depressions in the outline of the head (Fig 155) These depressions may be seen on the usual anteroposterior view with the arm in marked internal or external rotation or on axillary views taken by directing the x-ray beam upward from the axilla against a film casette placed above the shoulder No treatment is necessary or of any avail beyond treatment of the underlying dislocation

In young children with a history of injury to the shoulder region, it is important to remember that the humeral head is formed by the union of two separate epiphyseal centers, one for the medial and one for the lateral portion of the head The former is usually present at birth while the latter appears during the second half

tends to just beyond the site of the fracture and its distal end extends beyond the skin of the shoulder The fragments are then manually reduced and the intramedullary device is driven into the medial fragment a sufficient distance to immobilize the fractured ends firmly The portion of the pin that projects beyond the skin is cut so that the pin ultimately comes to lie beneath the skin The skin wound is then closed and the arm is immobilized in a figure-of-eight Velpeau, or Sayre dressing The pin may be left in situ or may be removed after union has been completed, usually within four to six weeks (Figs 153 and 154)

Fractures of the lateral or medial extremities of the clavicle are usually not associated with any marked displacement, because of the stabilizing action of the coracoclavicular and rhomboid ligaments Treatment of these fractures involves simple immobilization until pain has subsided

CHAPTER 13

Fractures of the Humerus

Fractures of the humerus arise as a result of direct or indirect trauma Those that occur above a line extending approximately between the levels of insertion of the teres major and the pectoralis major muscles are considered as fractures of the upper end Those occurring below a line that lies slightly above the condylar prominences are considered as fractures of the lower end Between these upper and lower limits, fractures are considered as being of the shaft

FRACTURES OF THE UPPER END

These include fractures of the head, the tuberosities and the anatomical neck and surgical neck of the humerus They usually occur in varying degrees of abduction of the arm and result in correspondingly different types and extent of fractures

Fractures of the Head

Isolated fractures of the head are extremely rare and are probably best treated by traction under the molding influence of motion *Infractions of the humeral head* are on the other hand rather common They usually occur in association with chronic dislocations of the shoulder and may be diagnosed roentgenographically as depressions in the outline of the head (Fig 155) These depressions may be seen on the usual anteroposterior view with the arm in marked internal or external rotation or on axillary views taken by directing the x-ray beam upward from the axilla against a film casette placed above the shoulder No treatment is necessary or of any avail beyond treatment of the underlying dislocation

In young children with a history of injury to the shoulder region it is important to remember that the humeral head is formed by the union of two separate epiphyseal centers one for the medial and one for the lateral portion of the head The former is usually present at birth while the latter appears during the second half

FIG 155 Infraction of the humeral head The normal globular appearance of the humeral head is interrupted by the appearance of a depression (See also Fig 146)

FIG 156 Fracture of the greater tuberosity There is slight downward displacement of the fragment resulting from a direct blow on the shoulder

of the first year to unite with the earlier center Occasionally this line of union may be visualized and present the appearance of a longitudinal fracture of the epiphysis (Fig 29)

FRACTURES OF THE TUBEROSITIES

Fracture of the lesser tuberosity is a relatively rare condition Because of its protected position, it usually results from forced external rotation against the pull of the subscapularis muscle that acts to avulse either all or a part of the tuberosity Although the condition may be suspected on clinical grounds, definitive diagnosis

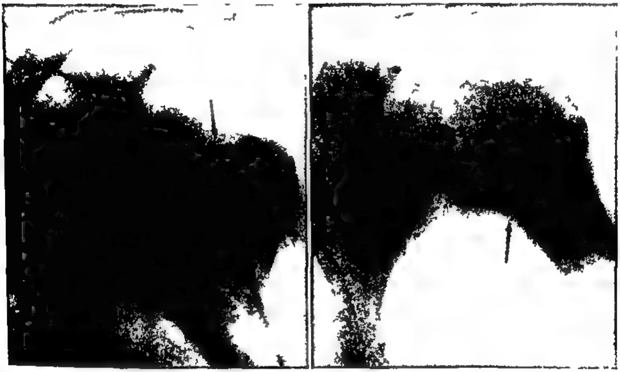


FIG 157 *Fracture of the greater tuberosity with dislocation of the shoulder* There is a subcoracoid dislocation of the shoulder associated with a longitudinal avulsion fracture of the greater tuberosity owing to the action of the cuff muscles (*left*) Reduction of the fracture occurred spontaneously after reduction of the dislocation (*right*)

is possible only on the basis of the x-ray The most expeditious method of treatment is by open operation The fragment with the attached subscapularis muscle can be easily exposed through the deltopectoral groove and securely fixed to the shaft by means of a screw Where surgical fixation is contraindicated, the arm should be immobilized in internal rotation with the arm behind the back until firm union has taken place

Fracture of the greater tuberosity is encountered with much greater frequency It may result from direct contusion of the shoulder, but is more commonly seen as the result of avulsions by the cuff muscles (Fig 156) It occurs in about 15 per cent of all simple dislocations (Fig 157) Differentiation between the avulsions mediated by each of the muscles entering into the musculotendinous cuff may be made

by appropriate x-ray exposure, but is of little practical significance Avulsion by the teres minor and the infraspinatus muscles is usually minimal, but even when of greater extent does *not materially jeopardize the function of the shoulder* Avulsion by the supraspinatus tendon may lead to displacement of the fragment upward beneath the acromion process and thus to mechanical blocking of abduction (Fig 158)

Where the displacement is minimal, no treatment other than simple support in a sling is indicated Gentle active motion should be instituted within one to two weeks to avoid periarticular adhesions that may be the consequence of organization

FIG 158 Avulsion fracture of the greater tuberosity The greater tuberosity has been displaced upward and lies between the humeral head and the acromion process just anterior to the coracoacromial ligament interfering with abduction of the shoulder The site of the avulsion is indicated by the flattening of the humeral head

of the extravasated blood Where displacement by the supraspinatus tendon is such as mechanically to impair motion, open operation and firm fixation of the fragment are indicated both to remove the mechanical impediment and to re-establish function of the supraspinatus tendon Provided the fragment is large enough this can be readily performed through a small longitudinal anterolateral muscle-splitting incision The fragment is transfixed by means of a screw or a wire (Fig 159) After four weeks gentle exercises may be instituted for a period of about two weeks, after which full use of the arm may be permitted if the roentgenogram shows evidence of firm union

FRACTURES OF THE ANATOMICAL NECK

In children, fractures through the anatomical neck are usually seen as epiphyseal separations In the newborn or young infants diagnosis is frequently difficult unless

FIG 159 Fracture of the greater tuberosity with dislocation of the shoulder Following reduction of the dislocation the greater tuberosity still showed marked separation and wiring by open operation was performed

FIG 160 Adduction epiphyseal separation of the upper end of the humerus The capital epiphysis is displaced medially and the upper end of the shaft is displaced laterally and upward (*left*) Following manipulation and traction in abduction almost perfect anatomical restitution has been accomplished The arm was maintained in abduction until healing had occurred (*right*)

the roentgenograms discloses displacement of the center of ossification of the medial portion of the head In older children the roentgenogram is usually typical with upward and outward displacement of the upper end of the shaft of the humerus (Fig 160) This may be classed as an adduction type of fracture and indicates the need for treatment in abduction Reduction of the fresh separation can be accom-

by appropriate x-ray exposure, but is of little practical significance Avulsion by the teres minor and the infraspinatus muscles is usually minimal, but even when of greater extent does not materially jeopardize the function of the shoulder Avulsion by the supraspinatus tendon may lead to displacement of the fragment upward beneath the acromion process and thus to mechanical blocking of abduction (Fig 158)

Where the displacement is minimal, no treatment other than simple support in a sling is indicated Gentle active motion should be instituted within one to two weeks to avoid periarticular adhesions that may be the consequence of organization

FIG 158 Avulsion fracture of the greater tuberosity The greater tuberosity has been displaced upward and lies between the humeral head and the acromion process just anterior to the coracoacromial ligament interfering with abduction of the shoulder *The site of the avulsion is indicated by the flattening* of the humeral head

of the extravasated blood Where displacement by the supraspinatus tendon is such as mechanically to impair motion open operation and firm fixation of the fragment are indicated both to remove the mechanical impediment and to re-establish function of the supraspinatus tendon Provided the fragment is large enough, this can be readily performed through a small longitudinal anterolateral muscle-splitting incision The fragment is transfixed by means of a screw or a wire (Fig 159) After four weeks, gentle exercises may be instituted for a period of about two weeks, after which full use of the arm may be permitted if the roentgenogram shows evidence of firm union

Fractures of the Anatomical Neck

In children, fractures through the anatomical neck are usually seen as epiphyseal separations In the newborn or young infants, diagnosis is frequently difficult unless

FIG 162 Abduction fracture of the anatomical neck of the humerus In the adult fracture of the anatomical neck is similar to epiphyseal separation in the child *A*, and may be associated with supraglenoid dislocation of the humerus Reduction may usually be accomplished by adduction of the arm after reduction of the dislocation *B*

They usually become realigned on reduction of the dislocation When impacted, they neither require nor are amenable to any efforts at reduction (Fig 162)

Fractures of the Surgical Neck

Fractures of the surgical neck are the most common of all fractures about the upper end of the humerus For practical purposes, these fractures may be subdivided into the adduction and abduction types (Fig 163) In young children, fractures of the adduction type seem to be the rule, although abduction fractures may occur (Fig 164) Where the malalignment is minimal, no effort need be made at realigning the axes of the fragments, since any malalignment will be amply overcome by the normal growth of the bone Where there is marked angulation, however the adduction fractures should be treated on an abduction splint, while the abduction fractures may be fixed to the side of the trunk over an axillary pressure pad Healing is usually sufficiently firm within four to six weeks to permit mobilization of the shoulder

In adults both the abduction and adduction fractures occur The *adduction* type (Fig 165), characterized by adduction of the humeral shaft with respect to the axis of the head, must be treated in abduction either on an abduction splint or by balanced traction Failure to correct the malalignment will lead to limitation of abduction that may be so disabling as to justify freeing of any existing impaction Union usually is sufficiently solid within four to six weeks to permit gradual resumption of passive and then active motion

The *abduction* type of fracture (Fig 166) should be treated in adduction over an axillary pad that should be just thick enough to realign the shaft without creating

plished without difficulty by abduction of the shaft while digital pressure is exerted against the head to prevent its dislocation during the manipulative procedure If the reduction is stable, the arm may be simply immobilized by a sling or swathing to the chest wall If, however, there is any tendency toward recurrence of the separation on postoperative x-ray films, the arm should be maintained in abduction either

FIG 161 Abduction epiphyseal separation of the upper end of the humerus The capital epiphysis is displaced laterally and there is a small triangular fracture of the lateral portion of the upper end of the humeral shaft which is displaced medially (*left*) The axis of the capital epiphysis and the axis of the humeral shaft make an inwardly directed angle Following manipulation and traction in adduction almost perfect anatomical restitution has been accomplished (*right*) The arm was maintained in adduction over an axillary pad

on an abduction splint by balanced traction in the recumbent position, or by overhead fixation in a plaster of Paris spica for a period of about four weeks

Occasionally, epiphyseal separations may be of the abduction variety, with the shaft displaced medially (Fig 161) Like the abduction fracture this type of epiphyseal separation must be treated in adduction with an axillary pad to maintain counterpressure against the shaft of the humerus

In adults fractures of the anatomical neck are rare and occur usually in association with shearing stresses that result in dislocation of the glenohumeral joint

FIG 165 Adduction fracture of the surgical neck in an adult It is clear that adduction of the shaft will merely tend to further malalignment This type of fracture must be treated in abduction either on an abduction splint or by balanced traction in bed

FIG 166 Comminuted abduction fracture of surgical neck Good axial alignment was obtained by adducting the arm over an axillary pressure pad which tends to displace the upper end outward and so to re-establish alignment

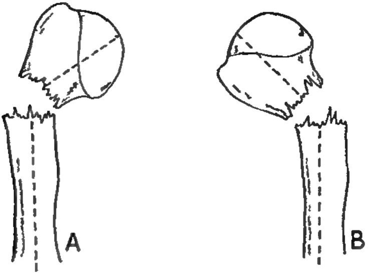


FIG 163 Adduction and abduction fractures at the upper end of the humerus The *adduction* fracture is characterized by adduction of the shaft and the formation of an outwardly directed angle between the axes of the fragments, *A* This type of fracture must be treated by *abduction* of the distal fragment The *abduction* fracture is characterized by abduction of the shaft and the formation of an inwardly directed angle between the axes of the fragments *B* This fracture must be treated by *adduction* of the distal fragment

FIG 164 Adduction fracture of the surgical neck in a child The axes of the upper and lower fragments make an angle directed outward The irregularity noted in the outer end of the acromion process is not a fracture but represents the normal ossification of this portion of the bone

Fig 165 Adduction fracture of the surgical neck in an adult It is clear that adduction of the shaft will merely tend to further malalignment This type of fracture must be treated in abduction either on an abduction splint or by balanced traction in bed

Fig 166 Comminuted abduction fracture of surgical neck Good axial alignment was obtained by adducting the arm over an axillary pressure pad which tends to displace the upper end outward and so to re establish alignment

FIG 167 Abduction fracture of the upper end of the humeral shaft This fracture was improperly treated for a period of over two weeks on an abduction splint *A* Sufficient callus had formed to prevent perfect anatomical alignment but by adduction of the distal fragment the axial alignment was improved *B*

the opposite deformity The arm may be fixed against the bony thorax until the acute symptoms have subsided and there is evidence of at least early union Thereafter the arm may be supported in a sling and gentle gradual motion should be encouraged Under no circumstances should these fractures be treated in abduction, since it tends to maintain the malalignment (Fig 167)

In both of these fracture types motion should be instituted as early as is possible so as to combat the tendency toward periarticular fibrosis that may be more disabling than the malalignment itself Mobilizing exercises should be performed with the trunk flexed at the hips and the arm hanging downward under the influence

of gravity Gentle rotatory motions in widening circles serve the same purpose as overhead abduction

Where there is evidence of periarticular fibrosis, manipulation of the shoulder may become necessary Manipulation is a valuable though dangerous procedure Bones have been fractured and brachial plexus paralyses have resulted from this maneuver Where manipulation is absolutely necessary, however, it must be performed After a fracture, it should not be undertaken until at least six weeks have elapsed and the patient should be forewarned of the dangers, including the possibility of refracture of the humerus

Fracture-dislocations of the Shoulder

The coexistence of a glenohumeral dislocation with fracture of the upper end of the humerus immeasurably increases the therapeutic difficulties Indeed, some

Fig 168 Resection of the humeral head Following a comminuted fracture with dislocation of the humeral head the head was resected This resulted in a painful joint with marked limitation of motion This procedure is never necessary in the treatment of acute or subacute fracture dislocations

surgeons have even recommended resection of the humeral head because of inability to control the small and frequently comminuted capital fragment This method is to be heartily deprecated particularly in the acute or subacute fracture-dislocations It results in a painful joint in which motion is markedly limited (Fig 168) Only in chronic cases where reduction of the dislocation cannot be anticipated and where a firmly fixed and malunited fracture exists should it be necessary to decide between surgical excision of the head and surgical fusion of the joint

A number of different methods of treating the fracture-dislocations have been described Fortunately, the classical method of Kocher is not applicable in the majority of instances The method is unphysiological and unnecessarily brutal and, since it may in itself lead to spiral fracture of the shaft should not be used even in the simple dislocations (Fig 169) The Hippocratic method, traction with the foot in the axilla acting to lever the head out of its subcoracoid position has been de

Fig 169 Spiral fracture of the upper end of the humerus This fracture occurred during the application of the Kocher maneuver for reduction of a subcoracoid dislocation (*left*) The dislocation was reduced by the method described in the text (see Fig 171) and the patient was immobilized in a Velpeau dressing with complete correction of both the fracture and the dislocation (*right*)

scribed as the safest method in that it tends to avoid additional traction damage to the neurovascular structures that are already stretched over the dislocated head It has been criticized because it may result in upside-down reduction of the head in which the articular surface of the head points downward and the fractured surface is in the glenoid cavity This is unquestionably because traction is exerted on the long scapulohumeral muscles but is not transmitted to the short cuff muscles that fix the head in the abnormal position In this respect the Jones method of exerting traction in the overhead position is more rational, but it has been criticized as dangerous because of the possibility of traction injury to the vessels and nerves

It is as a consequence of these objections that the method of traction pulsion against the head in the overhead position was recommended This method depends upon recognition of the fact that, in any position except that of complete overhead abduction, one or another of the perihumeral group of muscles acts at cross purposes with others of the group In the overhead position, however, all the muscles can be divided into four groups, each of which may be considered as lying on the surface of a cone, the apices of which are situated on the axis of the extended upper extremity (Fig 170) The first group is constituted by the cuff muscles—the subscapularis the teres minor, the supraspinatus, and the infraspinatus muscles The second group is made up by the latissimus dorsi the teres major, and the pectoralis major muscles The third group comprises the deltoid and the coracobrachialis muscles, while the fourth group, extending beyond the elbow joint comprises the biceps and triceps muscles

In the overhead position of arboreal brachiation the resultant of these muscles acts in an antigravitational manner to prevent tearing away of the trunk from the fixed upper extremity No muscle acts at cross purposes to any other and pressure directed against the head coaxially with the resultant of the four groups of muscles is the most efficient and physiological means of reducing any subglenoid dislocation or fracture-dislocation The essence of the method lies not in the traction but rather in the elimination of the multidirectional action of the scapulohumeral muscles, so that the head may be pushed into its normal position

In acute cases these maneuvers frequently can be carried out without the use of any anesthetic It is important to gain the patient s confidence by the assurance that little or no pain will be experienced No pain will be caused if the various steps of the procedure are carried out gently and, above all slowly in the following manner

For a dislocation of the right shoulder, the surgeon facing the patient, grasps the clavicle with the fingers of the right hand, while the thumb is placed firmly against the dislocated head to prevent its movement during the act of elevating the arm With the left hand the patient s elbow is gradually abducted until the whole arm is upright overhead The dislocated humeral head is then gently pushed upward with usually gratifying results and without malalignment of the fractured fragments Thereafter the fracture is treated like any other abduction or adduction fracture without dislocation For a fracture of the left side, the surgeon s left hand is used to fix the humeral head while the elbow is elevated by his right hand (Figs 171 and 172)

One word of caution must be emphasized No dislocation whether simple or associated with a fracture should be touched until a very careful neurological examination for peripheral nerve injury has been made Isolated traction paralysis of the axillary or ulnar nerves and even complete avulsion of the brachial plexus have been seen after dislocations of the shoulder Such lesions occur in about 15 per cent of all dislocations and failure to recognize and note these findings before manipulative reduction has been attempted may occasion the unwary surgeon more than simple embarrassment

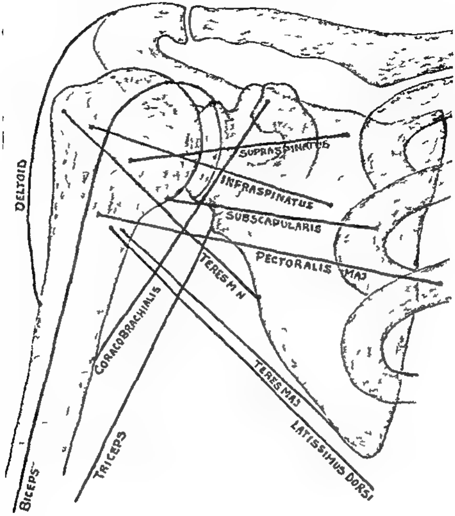


FIG 170 Arrangement of the muscles about the shoulder In the anatomical position (*above*) there is no consistent arrangement of the muscles In the overhead position (see opposite page) however the axis of the humerus is collinear with the axillary border of the scapula and all the scapulohumeral muscles can be grouped into four separate cones the axes of which are collinear with that of the humerus (Reproduced from Milch H Dislocations and fracture dislocations of the shoulder *J Bone & Joint Surg 31A* 173 1949)

FRACTURES OF THE SHAFT OF THE HUMERUS

Fractures of the humeral shaft have been defined as occurring in that portion of the bone between the insertion of the teres major and pectoralis major muscles and the condylar flare of the lower end of the humerus Borderline fractures that occur below the level of the surgical neck and above the site of attachment of the

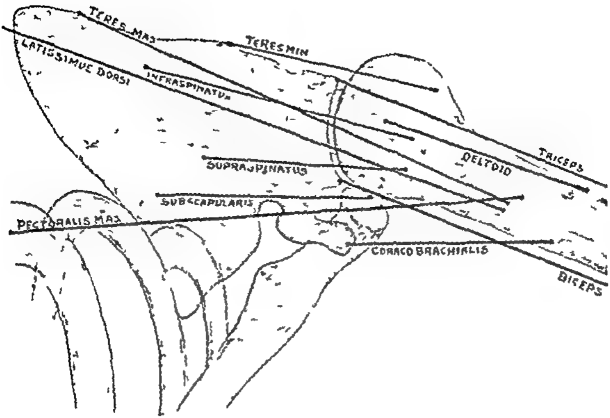


FIG 170 (Continued)

pectoralis major muscle present the characteristics of surgical neck fractures of the abduction or adduction types and are to be treated in similar manner (Figs 173 and 174)

Fractures of the upper end of the shaft may occur in the newborn as the result of obstetric maneuvers Generally these need cause no alarm, since they are readily diagnosed They can be easily reduced manually and retained without difficulty by means of lightly padded tongue-depressor splints held to the arm by encircling adhesive tape strips

In adults fractures of the shaft are frequently the cause of considerable concern both because of the possibility of injury to the radial nerve, which encircles the mid-portion of the bone and because of delayed union or nonunion to which the humerus is especially prone The classical method of reducing and retaining these fractures is by balanced traction suspension with the patient supine in bed (Figs 51 53 and 175)

Traction strips are applied to the lower end of the arm, extending to about the level of the fracture and the arm is abducted to ninety degrees Traction weights of three to six pounds are usually sufficient to restore alignment of the fracture In order to permit mobility of the elbow joint the forearm is flexed to about ninety degrees and traction strips are applied to the level of the elbow Weights of one to two pounds suspended over an overhead pulley serve to maintain the position of the forearm without interfering with motion of the elbow (Fig 176) Occasionally,

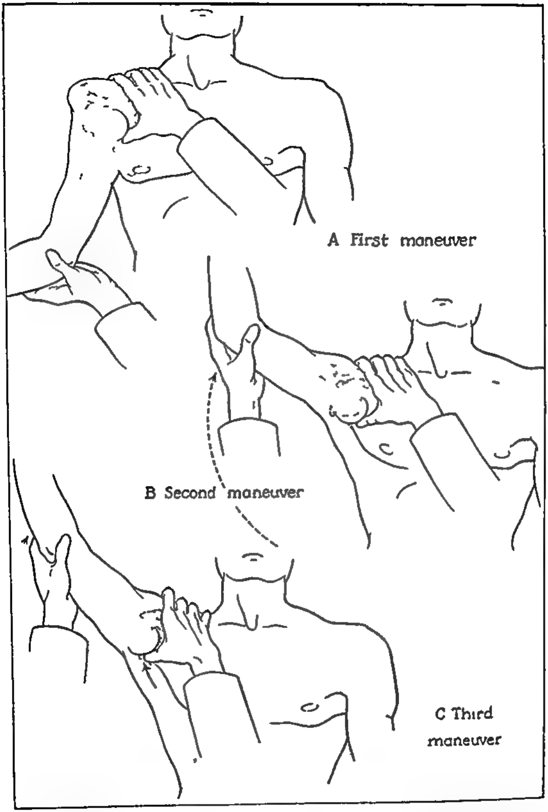


FIG 171 · Traction pulsion method for reduction of subglenoid dislocations of the humerus The dislocated humeral head is fixed in the first maneuver while the humerus is abducted during the course of the second maneuver In the third maneuver the humeral head is gently pushed into the glenoid with the assistance of slight upward traction on the arm (Reproduced from Milch H Treatment of dislocations of the shoulder *Surgery* 3 732 1938)

FIG 172 Comminuted fracture dislocation of the humeral head The fracture dislocation (*left*) was reduced by the traction pulsion method and alignment was maintained by balanced traction in forty five degrees of abduction (*right*)

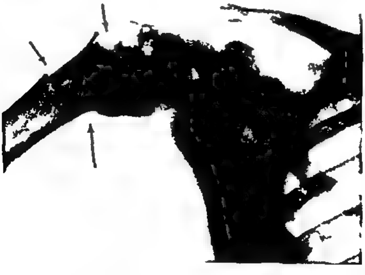


FIG 173 · Comminuted fracture of the upper end of the humeral shaft in a child There is a longitudinal fracture of the lesser tuberosity with separation of the capital epiphysis and a transverse fracture of the upper end of the humeral shaft Treatment was in abduction and balanced traction

it has been found that motion of the patient in bed unduly disturbs the fixation of the fragments and so retards healing To prevent this, it has been found desirable to apply a simple wooden splint along the posterior aspect of the humerus

The difficulty in these cases is primarily that of retention rather than of re alignment of the fragments Many different methods, from simple splinting to in tramedullary nailing, have been recommended In fractures with long trajectories

Fig 174 Abduction fracture of the upper end of the humeral shaft Displacement of the distal fragment probably occurs under the ac tion of the pectoralis major muscle and treat ment must be in adduction to relax this muscle and to permit realignment of the fragments

with minimal displacement, splinting by means of plaster of Paris slabs, coaptation splints or immobilization against the trunk by means of a Velpeau bandage is eminently satisfactory (Fig 177) The hanging cast method (Fig 89) has re ceived wide application within recent years As in the use of the Jones humerus splint it depends on the application of gentle downward traction within the sleeve formed by the surrounding musculature to secure alignment without excessive dis- traction of the fracture ends It is invaluable particularly in the treatment of el- derly patients in whom prolonged bed rest is contraindicated

While the method has the advantage of permitting early ambulation it has cer-

FIG 175 Balanced suspension for fractured humeral shaft Simple Buck s extension is applied to the distal fragment up to the level of the fracture The elbow is flexed to ninety degrees and suspended from an overhead frame The side of the bed is elevated to increase countertraction (See also Fig 53)

FIG 176 Comminuted fracture of the humeral shaft This fracture was treated by balanced traction suspension with satisfactory union of the fragments

FIG 177 Comminuted spiral fracture of the humeral shaft (*Left*) This was treated by immobilization on a metallic splint and fixation against the trunk by means of a Velpeau dressing (*right*)

tain drawbacks that are often overlooked Because the traction force is gravitational it necessitates sleeping in the seated position which youngsters do not readily maintain It is more happily applied to fractures of the upper half of the humeral shaft though it may be and has been applied to fractures of the lower half It is not immune to the reproach of distraction and should not be used without constant x ray control (Fig 178) Probably more important is the fact that it imposes an internal rotation of the lower fragment that results in a torsional malalignment This can occasionally be overcome by incorporating a wing in the plaster mold to prevent internal torsion (Fig 90) Finally in a number of cases, probably because of excessive motion, it seems to have delayed union in patients whose fracture con-

Fig 178 Oblique fracture of the humeral shaft Distraction of the fragments has occurred during treatment by the hanging cast method

Fig 179 Oblique fracture of the humeral shaft This fracture was originally treated in a hanging cast with distraction of the fragments Prompt union followed removal of the hanging cast and treatment in balanced suspension

solidated promptly after substituting balanced traction for the hanging cast (Fig 179)

In fractures in which bony apposition cannot be obtained, the likelihood of muscle interposition must be suspected and justifies open operation (Fig 180) Similarly, in fractures that are unstable after reduction and in short spiral or trans verse fractures where nonunion is more to be feared, open reduction and fixation

FIG 180 Spiral fracture of the humeral shaft There were signs of radial nerve palsy and at open operation interposition of soft tissue including the radial nerve was found between the fractured fragments The fracture was plated with prompt healing and gradual recession of the radial nerve symptoms

by Parham bands, metallic plates, or other devices is the procedure of choice (Fig 181) Where multiple fractures of the shaft have occurred, fixation by intramedullary nailing may convert a desperate into a relatively hopeful situation (Fig 182)

Nonunion is a not uncommon consequence of fracture of the humeral shaft Whether it is to be attributed to circulatory disturbance, to inadequate or contrariwise, to excessively firm fixation its occurrence is bound to tax the technical skill, the ingenuity and the luck of the most accomplished surgeon Bone grafting alone is frequently unsatisfactory but when combined with plate fixation is more apt to be successful (Fig 183)

FIG 181 Comminuted fracture of the humeral shaft This fracture was reduced at open operation and maintained by means of a Lane plate

FIG 182 Multiple fractures of the humeral shaft Because of inability to realign the fragments by closed methods intramedullary fixation was performed (Courtesy of Dr J Buchman)

Injury to the radial nerve may occur in association with any fracture situated within the middle two thirds of the humerus As the radial nerve passes from the upper and medial aspect of the arm to its lower and lateral aspect, it lies in the musculospiral groove where it may be injured either primarily or as a result of compression by excessive callus formation As it passes from the posterior to the anterior fascial compartments of the arm the nerve is firmly fixed by the external intermuscular septum and is subject to traction especially on manipulation of lower

FIG 183 Old fracture of the humeral shaft There was nonunion with marked loss of substance at the fracture site A cortical bone graft was placed between the two ends of the bone and firm fixation was secured by means of a Wenger type of double plate

shaft fractures Sensory disturbances in the distribution of the radial nerve and inability to extend the wrist and the proximal phalanges are the usual signs Since extension of the middle and distal phalanges of the fingers is in large part evidence of the integrity of the median and ulnar nerves the ability to extend these phalanges without extension of the proximal phalanx will only bring solace to the unwary examiner Where there is assurance of interruption or compression of the nerve operative exploration is indicated Not every radial nerve palsy must inevitably be operated upon and it is frequently better judgment to temporize until the possibility of return of function can be excluded before proceeding to surgical exploration

CHAPTER 14

Fractures about the Elbow

The existence of an injury about the elbow joint involves the necessity of accurate diagnosis of the part injured and a differentiation between simple fractures of the bones entering into the elbow joint and those that are associated with dislocations

FRACTURES OF THE LOWER END OF THE HUMERUS

These fractures comprise all those that occur between the level of the condylar flare and the inferior articular surface They include the epiphyseal separations, supracondylar and dicondylar fractures, intercondylar fractures avulsions of the epicondyles, and isolated fractures of either condyle

Epiphyseal Separations of the Lower End

Epiphyseal separations of the lower end of the humerus are fortunately rare, occurring usually during birth as a result of obstetrical maneuvers They are difficult to diagnose and resemble posterior dislocations of the elbow They may be suspected in the newborn whose elbow is tender, swollen, and preternaturally mobile with the forearm held in flexion and pronation Because of the absence of any ossification centers for the lower humeral epiphysis at this early age, the roentgenogram presents the evidence of a dislocation without any signs of a fracture of the bones entering into the elbow joint (Fig 184) Treatment should be immediate and should consist of gentle traction on the forearm combined with appropriate pressure against the epiphysis to effect reduction Immobilization for a short period of time should be carried out in extension and flexion should be permitted after ten or twelve days After another ten or twelve days of immobilization in flexion active motion may be encouraged

Supracondylar and Dicondylar Fractures

Supracondylar and dicondylar fractures differ from one another in that in the former (1) the fracture line passes above the level of the olecranon or coronoid

FIG 184 Epiphyseal separation of the lower end of the humerus Anteroposterior view of the lower end of the humerus in a two day old infant There is no evidence of fracture but the entire forearm and lower end of the humerus are dislocated upward and medially (Reproduced from Camera R Il distacco epifisario totale ostetrico dell ex tremita inferiore dell omero *Chir d org di movimento 33* 313 1949)

FIG 185 Flexion type of supracondylar fracture The distal fragment is displaced anteriorly (*left*) Treatment should be in extension since flexion would tend to increase the deformity This fracture was converted into an extension type of fracture by manually displacing the fragment posteriorly (*right*) (Reproduced from Milch H Supracondylar fracture *Bull Hosp Joint Dis 11* 187 1950)

fossae, and (2) there is sufficient area of fracture surface to permit adequate stabilization of the fracture after reduction while in the latter the fracture occurs through the thinnest portion of the bone so that both reduction and maintenance of the fracture after reduction are most difficult

Both supracondylar and dicondylar fractures may be divided into two types (1) the *extension* type, in which the fracture line is directed from below and an

teriorly to above and posteriorly, with posterior displacement of the distal fragment and (2) the *flexion* type, characterized by exactly opposite appearance In general extension fractures should be reduced and immobilized in a position of flexion, while flexion fractures should be treated in extension

Flexion fractures are far less common than extension fractures While their treatment in extension can usually be undertaken without necessary loss of the ability to flex the elbow, the possibility of this complication cannot be gainsaid

FIG 186 Converted supracondylar fracture of the flexion type Lateral view (*left*) and anteroposterior view (*right*) after healing Following conversion of the flexion into an extension type of fracture the extremity was immobilized in the Jones position with the elbow in flexion (Reproduced from Milch H Supracondylar fracture *Bull Hosp Joint Dis 11* 187 1950)

This complication may be minimized by flexing the elbow as soon as there is assurance of fixation of the fragments or it may be entirely obviated by careful conversion of the flexion into an extension type of fracture This can be accomplished under anesthesia by displacing the distal fragment posteriorly and then treating the elbow in flexion as for the more common extension type of fracture (Figs 185 and 186)

Treatment of extension types of supracondylar or dicondylar fracture by the hyperflexion method of Jones is in widest use and avoids the necessity for hospitalization The fractured fragments are usually not impacted, but because of the excessive swelling, which is characteristic of these fractures, roentgenographic con-

trol of the accuracy of reduction is essential It is particularly in these fractures that rotation of the distal fragment may simulate transpositional deformity Great care must be taken to flex the forearm so that its axis is collinear with that of the arm upon which it is flexed Any deviation either laterally or medially is representative of a corresponding torsional malalignment owing to rotation of the distal fragment This may permit excess callus formation that will limit flexion and extension of the elbow by decreasing the effective depth of the olecranon and coronoid fossae (Fig 187)

After realignment of the fragments in Jones's position, the upper extremity should be immobilized in a posterior molded splint or by a simple figure-of eight

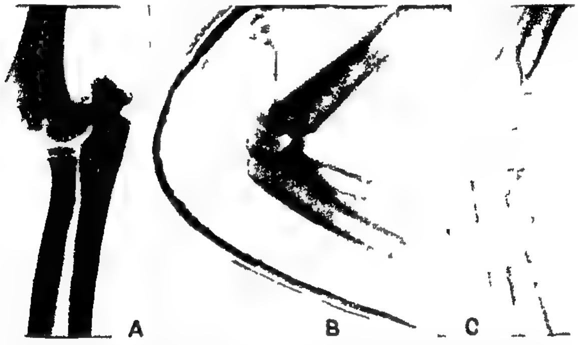


FIG 187 Extension type of dicondylar fracture *A* There is posterior and medial displacement of the distal fragments *B* treated in flexion by the Jones method There is incomplete reduction and the persistence of a torsional deformity *C* as a consequence there has been excessive callus formation with filling of both olecranon and coronoid fossae and limitation of both flexion and extension

dressing in the maximum degree of flexion consistent with maintaining the circulatory integrity of the fingers

Circulatory impairment may occur within a relatively short period of time and the patient must be kept under careful observation to forestall the development of a disastrous Volkmann's ischemic paralysis Unusual cyanosis or blanching of the skin swelling or numbness of the fingers and a decrease in the quality of the radial pulse in the involved extremity should be recognized as warning signs In such event, the degree of flexion must be reduced immediately even at the risk of loss of position of the reduced fracture (Fig 188) Sympathetic ganglion blockade to relieve vasospastic phenomena either as a prophylactic measure or for definitive

treatment of the condition is indicated Even when anatomical reduction has been achieved however, limitation of flexion or extension may result from the deposition of excessive amounts of reparative callus in either of the fossae (Fig 189)

Flexion treatment is more safely carried out by the Dunlop method than by the Jones method In view of the potential danger of these fractures, the necessary hospitalization that the Dunlop method entails should be considered advantageous

Fig 188 Extension type of supracondylar fracture This fracture was treated by the Jones method Because of circulatory impairment the flexed position had to be reduced There was loss of position with obliteration of both fossae by excessive callus Marked limitation of flexion and extension resulted

Fig 189 Extension type of supracondylar fracture Treated in flexion by the Jones method with excellent reduction of the fracture but with excessive callus formation obliterating the olecranon fossa and resulting in limitation of extension

rather than undesirable (Fig 57) The patient is treated in the recumbent position with the arm abducted to ninety degrees from the trunk Adhesive traction strips are applied to the forearm and traction (about six pounds) is made over a pulley so arranged as to flex the forearm to between thirty and forty degrees from the completely extended position To prevent elevation of the entire extremity, a sling weighted with about three pounds is suspended over the lower part of the arm The position must of course, be constantly controlled by roentgenographic examination

The improvement in results, however, more than compensates for the increased cost and discomfort to the patient or to the patient's family (Fig 190)

In young patients, irreducible malalignment or excess callus formation leading to limitation of motion may be expected to show gradual improvement owing to the remodeling power inherent in actively growing bone In adults, a similar disability

FIG 190 Extension type of dicondylar fracture In the two left pictures there is *posterior and medial displacement of the distal fragment, in the two right pictures* treatment was by Dunlop s method of traction There is no evidence of torsion and the normal anterior angulation of the lower end of the humerus has been restored

FIG 191 Old malaligned flexion type of supracondylar fracture There is almost complete limitation of flexion and extension by impingement of the coronoid process against the projecting anterior surface of the distal fragment and of the olecranon process against the lower end of the humeral shaft

caused by projecting bone blocks presents a justifiable indication for operative correction (Fig 191) This can be easily undertaken through either lateral or medial incisions or both exposing the anterior and posterior aspects of the lower end of the humerus To prevent refracture resections of the bony projections are completed by a reciprocating saw in preference to the osteotome and mallet In no event should any effort be made to excise callus ossifying hematoma, or muscle until all evidence of activity has subsided (Fig 192) In many instances the masses will

FIG 192 Intramuscular hematoma following supracondylar fracture The fracture has been well reduced The calcified hematoma on the volar aspect of the arm limited flexion and was excised

FIG 193 Cubitus valgus with delayed ulnar nerve palsy Fifty years after a fracture of the lower end of the humerus this patient manifested signs of ulnar nerve palsy which was treated by anterior transplantation of the ulnar nerve

either shrink or disappear entirely without treatment and, in any event, premature interference can only serve to aggravate the condition

Delayed ulnar nerve palsy is a not uncommon sequel of these fractures It usually occurs many years after the fracture has been long forgotten and is characterized by the appearance of paresthesias and weakness in the distribution of the ulnar nerve (Fig 193) The palsy is in all probability due to an intraneural or perineural fibrosis resulting from constant irritation of the ulnar nerve over some slight irregularity at the site of the earlier fracture The treatment of this condition is by transplantation of the nerve from its normal position behind the medial humeral condyle to an anterior position

Intercondylar T- or Y-Shaped Fractures

Intercondylar fractures, in contradistinction to supracondylar or dicondylar fractures are best treated by open operation They are intraarticular fractures and the necessity for anatomical reduction takes precedence over any but vital considerations Reposition of the fragments can be accomplished through small lateral and medial incisions and definite fixation can be completed by means of Kirschner wires or screws placed through the epicondyles without additional damage to the articular surfaces (Fig 194)

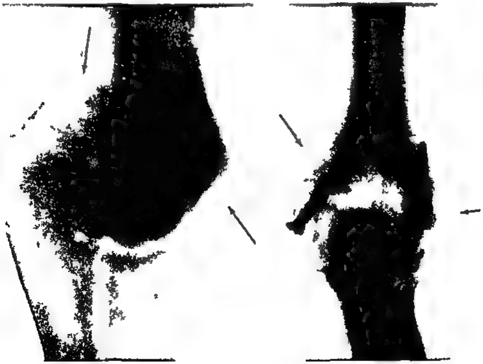


Fig 194 Intercondylar fracture There is medial and posterior displacement of both fragments (*left*) The fragments were reduced at open operation and fixed by screws with anatomical restoration of position (*right*)

Fractures of the Epicondyles

Fractures of the epicondyles may occur as the result of direct violence or muscle pull (Figs 195 and 196) The lateral epicondyle being much smaller than the medial is less often subject to fracture (Fig 197) Neither fracture needs any treatment other than simple immobilization for control of pain during the acute

Fig 195 Epiphyseal separation of the medial epicondyle There is minimal medial and upward displacement of the medial epicondyle (*left*) Despite this union did not occur even after the other epiphyses had closed (*right*)

Fig 196 Comminuted fracture of the lateral epicondyle No treatment other than simple immobilization in mid flexion was instituted The immobilizing cast was removed as soon as the acute symptoms of pain and swelling had subsided

FIG 197 Avulsion fracture of the lateral epicondyle This condition should not be confused with perihumeral calcification seen in so called tennis elbow (radiohumeral bursitis)

FIG 198 Old nonunited fracture of the medial epicondyle Despite the downward displacement of the fractured fragment there was no impairment of joint function (*left*) The patient however began to develop symptoms of ulnar nerve palsy The fragment was excised (*right*) and the ulnar nerve transplanted to the anterior compartment of the forearm The ulnar palsy subsided entirely without impairment of the strength of the forearm

phase Where a large fragment of the medial epicondyle is broken off, resuture or wire fixation is indicated Nonunion may occur Because the ulnar nerve passes directly behind the medial epicondyle it may be injured at the time of fracture, or signs of delayed ulnar palsy may develop many years later In such event the epicondyle should be removed through a medial incision (Fig 198) The nerve may be transplanted if indicated and the flexor muscles should be carefully reattached at the termination of the procedure When the avulsed fragment is displaced

FIG 199 Old nonunited fracture of the medial epicondyle The patient developed numerous freely lying joint bodies (joint mice) with manifestations of arthritis in the elbow joint The joint mice and the epicondylar fragment were removed through a medial incision

downward so that it acts as a joint mouse or when it gives rise to other joint mice, medial arthrotomy for removal of the free fragments is indicated (Fig 199)

FRACTURES OF THE LATERAL CONDYLE

Fractures of the lateral condyle may arise as the result of the application of three different forces (1) an adduction force delivered against the outer aspect of the extended elbow (2) a longitudinal force transmitted upward along the radius, and (3) a longitudinal force delivered upward along the ulna

The first gives rise to an *adduction* type of fracture, in which the condylar fragment is displaced downward so that the forearm is deviated medially with reduction of the normal carrying angle This fracture may be reduced by closed manipulation

Fixation by a Kirschner wire is to be preferred, since it offers absolute assurance of retention without the necessity for immobilization of the elbow joint (Fig 200)

The latter two fracturing forces give rise to two types of *abduction* fracture (Fig 201) Transmission of the force along the radius impacts the medial raised border of the radial head against the capitellum humeri and results in Type 1 ab

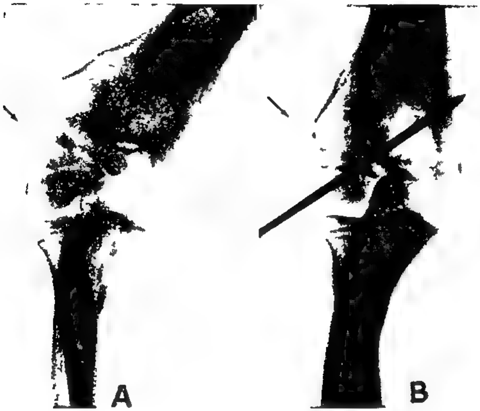


FIG 200 Adduction fracture of the lateral condyle (*A*) The fracture runs from above and laterally to below and medially enters the joint lateral to the trochlear groove and medial to the epicondylo trochlear sulcus The distal fragment consisting of the capitellum and the lateral condyle is displaced downward with a reduction of the car rying angle of the elbow (*B*) The fragment has been replaced and fixed in position by means of a Kirschner wire The carrying angle has been restored (Reproduced from Milch H Fractures of external humeral condyle *J A M A* *160* 641 1956)

duction fracture (Fig 202) The fracture line directed upward and outward extends obliquely into the elbow joint from laterally above to medially below The capitellar surface and a small lateral portion of the trochlear surface but never the whole of the lateral wall of the trochlea may be included in the fractured fragment

Transmission of the force along the ulna impacts the ulnocoronoid ridge against the deepest portion of the trochlear groove and leads to a Type 2 abduction fracture-dislocation As in the Type 1 fracture the fracture line is directed upward and outward and extends obliquely into the elbow joint from laterally above to medially below In contradistinction to the Type 1 fracture the fracture fragment consists

of the capitellar surface and *all* the lateral wall of the trochlea This results in loss of the lateral restraint and permits of lateral dislocation of the ulna

Some difference of opinion has been expressed as to the proper method of treatment of this Type 1 fracture When there is minimal displacement or rotation of the distal fragment, closed reduction appears to be feasible The difficulty in such

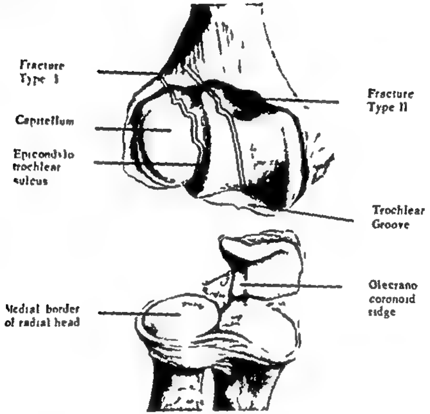


FIG 201 Abduction fracture types of the lateral condyle In both types, the fracture line is directed from above and laterally to below and medially In Type 1 fracture the fracture line passes lateral to the trochlear groove, while in Type 2 the fracture line passes through or medial to the trochlear groove Type 1 is a simple fracture in which the distal fragment is displaced upward and outward Type 2 is a fracture dislocation in which in addition to the displacement of the distal fragment, there is a lateral dislocation of the forearm at the elbow joint Type 1 fracture is caused by the wedge action of the raised medial border of the radial head Type 2 fracture dislocation is caused by the wedge action of the olecranocoronoid ridge

cases lies in the retention after the reduction All observers are agreed that the reduction is unstable Although some have immobilized the fracture in extension most surgeons continue to fix the elbow in right angled flexion This is in error as reference to the anatomy of the elbow joint will quickly reveal In flexion at ninety degrees both the coronoid and olecranon processes are free in the joint In acute flexion, only the coronoid process is buried deep in its fossa and by impingement

Fixation by a Kirschner wire is to be preferred, since it offers absolute assurance of retention without the necessity for immobilization of the elbow joint (Fig 200)

The latter two fracturing forces give rise to two types of *abduction* fracture (Fig 201) Transmission of the force along the radius impacts the medial raised border of the radial head against the capitellum humeri and results in Type 1 ab

FIG 200 Adduction fracture of the lateral condyle (*A*) The fracture runs from above and laterally to below and medially enters the joint lateral to the trochlear groove and medial to the epicondylo trochlear sulcus The distal fragment consisting of the capitellum and the lateral condyle is displaced downward with a reduction of the car rying angle of the elbow (*B*) The fragment has been replaced and fixed in position by means of a Kirschner wire The carrying angle has been restored (Reproduced from Milch H Fractures of external humeral condyle *J A M A* *160* 641 1956)

duction fracture (Fig 202) The fracture line directed upward and outward extends obliquely into the elbow joint from laterally above to medially below The capitellar surface and a small lateral portion of the trochlear surface but never the whole of the lateral wall of the trochlea may be included in the fractured fragment

Transmission of the force along the ulna impacts the ulnocoronoid ridge against the deepest portion of the trochlear groove and leads to a Type 2 abduction fracture dislocation As in the Type 1 fracture the fracture line is directed upward and outward and extends obliquely into the elbow joint from laterally above to medially below In contradistinction to the Type 1 fracture, the fracture fragment consists

against the lateral wall of the coronoid fossa stabilizes the joint against displacements in the coronal plane In extension the olecranon is buried deep in the olecranon fossa and, by similar impingement against the lateral wall of the olecranon fossa, affords stability against abduction or adduction displacements Since the position of acute flexion is impossible without risk of circulatory impairment, it is apparent that immobilization following closed reduction must be carried out with the elbow in extension

Where there is marked displacement or irreducible rotation, open operation and wire fixation should be undertaken within a relatively short time after injury (Fig 203) Delay of several weeks immeasurably increases the difficulty of reduction,

FIG 204 Type 1 abduction fracture of the lateral condyle The lateral condyle was resected with resulting overgrowth of the radial head weakness of the elbow and disturbance of the inferior radioulnar joint

because the fragment is then firmly imbedded in dense scar tissue, and of retention, because of the bone atrophy that almost invariably occurs Resection of the fractured fragment is to be condemned since it may lead to instability of the joint and overgrowth of the radial head (Fig 204)

While the direction of the fracture line in the simple Type 1 fracture is more or less parallel to that of the Type 2 fracture dislocation, it must be emphasized that in the latter the fracture line always enters the articular surface of the elbow joint at or medial to the deepest point of the trochlear groove (Fig 205) The consequence of this loss of the lateral supporting articular surface of the humerus is a *lateral dislocation* of the forearm It is this that differentiates the two types and establishes the therapeutic indication The Type 1 fracture may be treated either closed or open, the Type 2 fracture dislocation must be treated by open operation with fixation of the fractured fragment This imposes the necessity of early and accurate roentgenographic diagnosis to determine the type

FIG 202 Type 1 abduction fracture of the lateral condyle The distal fragment is displaced upward and laterally with increase in the carrying angle of the elbow If treated by closed methods this fracture should be immobilized in extension

FIG 203 Type 1 abduction fracture of the lateral condyle The fragment has been reduced and retained by a transfixing Kirschner wire

against the lateral wall of the coronoid fossa stabilizes the joint against displacements in the coronal plane In extension the olecranon is buried deep in the olecranon fossa and by similar impingement against the lateral wall of the olecranon fossa affords stability against abduction or adduction displacements Since the position of acute flexion is impossible without risk of circulatory impairment it is apparent that immobilization following closed reduction must be carried out with the elbow in extension

Where there is marked displacement or irreducible rotation, open operation and wire fixation should be undertaken within a relatively short time after injury (Fig 203) Delay of several weeks immeasurably increases the difficulty of reduction,

FIG 204 Type 1 abduction fracture of the lateral condyle The lateral condyle was resected with resulting overgrowth of the radial head weakness of the elbow and disturbance of the inferior radioulnar joint

because the fragment is then firmly imbedded in dense scar tissue and of retention because of the bone atrophy that almost invariably occurs Resection of the fractured fragment is to be condemned since it may lead to instability of the joint and overgrowth of the radial head (Fig 204)

While the direction of the fracture line in the simple Type 1 fracture is more or less parallel to that of the Type 2 fracture-dislocation it must be emphasized that in the latter the fracture line always enters the articular surface of the elbow joint at or medial to the deepest point of the trochlear groove (Fig 205) The consequence of this loss of the lateral supporting articular surface of the humerus is a *lateral dislocation* of the forearm It is this that differentiates the two types and establishes the therapeutic indication The Type 1 fracture may be treated either closed or open the Type 2 fracture-dislocation must be treated by open operation with fixation of the fractured fragment This imposes the necessity of early and accurate roentgenographic diagnosis to determine the type

FIG 205 Type 2 abduction fracture dis location of the lateral condyle The ulna is dis located laterally and its medial border makes a medially directed angle with the medial border of the trochlea The medial half of the ulnar sigmoid articulates with the lateral surface of the fractured trochlea The fractured lateral condyle is displaced upward and outward but maintains its articulation with the radial head This type of fracture whether recent or old cannot be treated by closed methods

In the normal adult the capitellum the epicondylo-trochlear sulcus and the trochlear groove between the walls of the trochlea can be readily visualized on the anteroposterior x ray In young children the roentgenogram is of little value for the demonstration of these anatomical landmarks (Fig 206) The center of ossification for the lateral condyle usually appears during the first postnatal year, but the center of ossification for the trochlea does not develop until after the seventh year While the epicondylotrochlear sulcus can be readily recognized, the trochlear groove is entirely cartilaginous and cannot be visualized In some instances, the

vital differentiation between Type 1 fracture of the lateral condyle, which may be treated closed, and Type 2 fracture dislocation which must be operated upon depends upon recognition of the forearm dislocation (Fig 207)

Failure to recognize the forearm dislocation and to institute prompt and proper surgical fixation inevitably results in a high degree of cubitus valgus (Fig 208) This late deformity is not amenable to simple osteotomy (Fig 209) By this

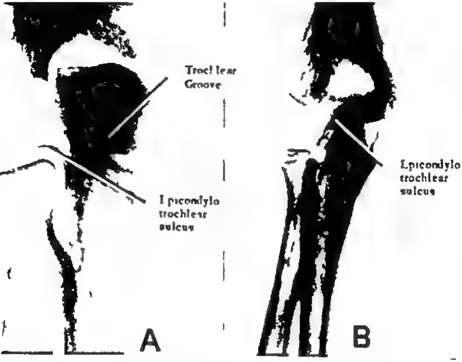


FIG 206 Normal anteroposterior views of the elbow joint *A* In the adult both the epicondylotrochlear sulcus and the trochlear groove are clearly visualized The raised medial border of the radial head is buried in the epicondylotrochlear sulcus and the wedgelike olecranocoronoid ridge is buried in the depths of the trochlear groove The medial border of the ulna is in alignment with the medial border of the trochlear *B* In the child only the epicondylotrochlear sulcus can be seen The center of ossification for the trochlea does not develop until after the seventh year The medial border of the ulna is in alignment with the medial border of the trochlea

method alone; even overcorrection of the angular deformity cannot obviate the unaesthetic appearance of the elbow This can be accomplished only by a somewhat more complicated procedure that combines an axial transpositional with the conventional type of angulational osteotomy (Fig 210)

The operation is carried out with the patient in the prone position A mid line incision with splitting of the triceps muscle exposes the site of the deformity The shaft of the humerus is transected at the level of the upper end of the displaced fragment and the distal cut surface of the humerus is notched For the correction of the cubitus valgus the apex of the inner cortex of the distal fragment is trans-

FIG 207 Anteroposterior roentgenograms of abduction fractures of the lateral condyle in a child In *A* Type 1 abduction fracture the medial border of the ulna and the medial border of the trochlea are collinear In *B* Type 2 abduction fracture dislocation the fragment appears to be similar to the fragment in *A* the Type 1 fracture The forearm however is displaced laterally and the medial border of the ulna makes a medially directed angle with the medial border of the trochlea The broken lines indicate the angular relationship of the arm and forearm In *B* there is increased valgus due to the dislocation of forearm

posed outward into this notch With this as a fulcrum the distal osteotomized fragment is angulated until adequate correction can be demonstrated by roentgenographic control The position is fixed by the insertion of Kirschner wires and the extremity is immobilized in plaster until firm bony union occurs Because of the fact that neither the joint nor the relationship between the fragments has been disturbed, the usually good range of motion is not impaired In the event of a concomitant delayed ulnar palsy anterior transplantation of the ulnar nerve may be performed at the same time (Figs 211 and 212)

FIG 208 Type 2 abduction fracture dis location of the lateral condyle There is marked displacement of the condylar fragment and overgrowth of the radial head The ulna is dis placed laterally and articulates with the frac tured surface of the trochlea leading to a marked cubitus valgus

FRACTURES OF THE MEDIAL CONDYLE

As with the lateral condyle three different types of fracture of the medial condyle have been described Except for a presumptive difference in the angle of in cidence of the fracturing force, which accounts for the upward and inward direction of the fracture line medial condylar fractures arise from the same types of force as generate lateral condylar fractures (1) an abduction force delivered against the inner aspect of the extended elbow, (2) a longitudinal force transmitted upward along the shaft of the ulna and (3) a longitudinal force transmitted upward along the shaft of the radius The first gives rise to an *abduction* type of fracture Comparable with what is seen in the lateral condyle, the medial condyle is displaced downward and the carrying angle of the forearm is increased Unless there has been marked displacement with rotation simple adduction suffices to reduce the

fragment Otherwise, open operative reduction with Kirschner wire fixation is immediately indicated, as in the external condylar fracture

The latter two forces give rise to *adduction* types of fracture Transmission of force along the ulna to a point on the articular surface of the humerus medial to the trochlear groove produces a simple adduction fracture of the medial condyle comparable to the Type 1 abduction fracture of the lateral condyle Failure to se-

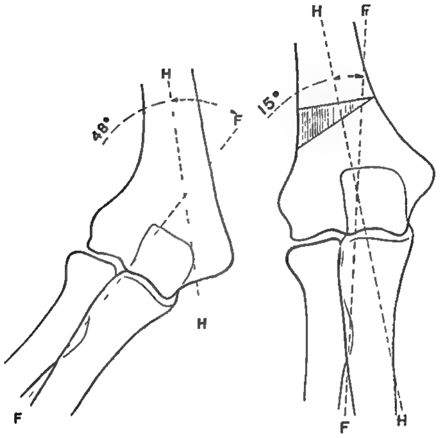


FIG 209 Cubitus valgus following Type 1 abduction fracture of the lateral condyle The carrying angle as measured between the axes of the arm and forearm is 48 degrees By removing a wedge of bone from the outer aspect of the lower end of the humerus the carrying angle has been reduced to the normal of about 15 degrees (Reproduced from Milch H Treatment of cubitus valgus *Clinical Orthopedics 6* 120, 1955

cure adequate reduction results in a cubitus varus deformity (Fig 213) This is usually amenable to simple osteotomy of the type shown for the treatment of simple cubitus valgus (Fig 209) This osteotomy should be performed along the inner aspect of the lower end of the humerus with an outward wedging of the distal osteotomized fragment to restore the carrying angle of the elbow Particular care must be taken to protect the ulnar nerve during the exposure of the medial condyle and if there is any danger of tension on the ulnar nerve as a result of increasing the valgus, the nerve should be transplanted anteriorly Resection of the medial condyle

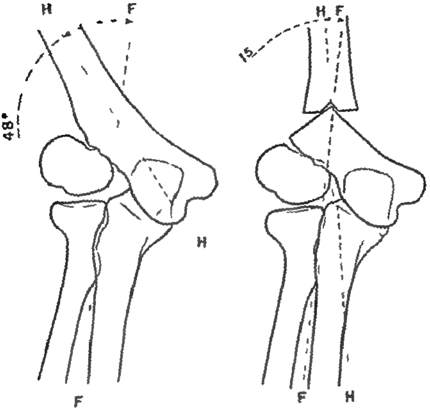


FIG 210 Cubitus valgus following Type 2 abduction fracture dislocation of the lateral condyle As in the Type 1 abduction fracture (Fig 209) the carrying angle is about 48 degrees By simple wedge osteotomy the carrying angle could be reduced to relatively normal but despite this the unesthetic prominence of the medial humeral condyle persisted and it was only after lateral transposition of the distal osteotomized portion of the humerus that the apparent cubitus valgus could be overcome (Reproduced from Milch H Treatment of cubitus valgus *Clinical Orthopedics 6* 120 1955)

should never be performed It results in a loss of the medial buttress to the olecranon and a permanent fixed cubitus varus deformity (Fig 214)

Transmission of the force to a point at or lateral to the trochlear groove produces Type 2 fracture dislocation of the medial condyle comparable to Type 2 fracture dislocation of the lateral condyle Treatment similar to that employed for fracture-dislocation of the lateral condyle is indicated (Fig 215)

In summary fractures through or medial to the trochlear groove can be only Type 2 abduction fracture dislocations of the lateral condyle, abduction fractures of the medial condyle or Type 1 adduction fractures of the medial condyle The former can be readily differentiated from the latter two by the presence of the dislocation component and the direction of the fracture line The latter two similarly may be readily differentiated clinically on the basis of the type of deformity (cubitus valgus or cubitus varus respectively) and roentgenographically on

FIG 211 Cubitus valgus following Type 2 abduction fracture dislocation of the lateral condyle Patient had a good range of motion despite the deformity but developed a late ulnar palsy (Before operation)

FIG 212 Correction of cubitus valgus owing to Type 2 abduction fracture dislocation of the lateral condyle A transpositional angulational osteotomy has been performed restoring the normal carrying angle

FIG 213 Cubitus varus resulting from old malunited Type 1 adduction fracture of the medial condyle The carrying angle is decreased owing to the upward displacement of the trochlear fragment This can be corrected by simple wedge osteotomy

the basis of the direction in which the condylar fragment is displaced (downward or upward respectively)

In a like manner, fractures passing lateral to the trochlear groove can be only adduction fractures of the lateral condyle, Type 1 abduction fractures of the lateral condyle, or Type 2 adduction fracture dislocations The latter is again readily identified by the presence of the concomitant dislocation and the direction of the fracture line, while the former two can be differentiated clinically on the basis of the observed carrying angle of the elbow (cubitus varus or cubitus valgus, respectively) and roentgenographically on the basis of the displaced position of the condylar fragment (downward or upward respectively) (Table 4)

FIG 214 Cubitus varus following Type 1 adduction fracture of the medial condyle The trochlear fragment has been completely resected leading to a fixed cubitus varus This should be corrected by simple wedge osteotomy

FIG 215 Type 2 adduction fracture dislocation of the medial condyle The trochlear surface has been dislocated into the joint space and there is medial dislocation of the forearm (*left*) Following open reduction and Kirschner wire pinning of the fractured trochlea anatomical restoration has been achieved (*right*) (Courtesy of Dr D Raskind)

TABLE 4.—Summary of Condylar Fractures of the Humerus

	Lateral condyle			*Medial condyle*		
Direction of fracturing force	adduction (vs lateral side)	upward along radius	upward along ulna	abduction (vs medial side)	upward along radius	upward along ulna
Type of fracture	adduction fracture	Type 1 abduction fracture	Type 2 abduction fracture dislocation	abduction fracture	Type 1 adduction fracture	Type 2 adduction fracture-dislocation
Direction of fracture line	*Laterally above to medially below*			*Medially above to laterally below*		
Relation of fracture line to Trochlear groove	lateral	lateral	through or medial	through or medial	through or medial	through or lateral
Epicondylo trochlear sulcus	through or medial	through or medial	medial	medial	medial	through or medial
Displacement of condylar fragment	downward	upward	upward	downward	upward	upward
Composition of condylar fragment	capitellum + part lateral wall trochlea	capitellum + part lateral wall trochlea	capitellum + entire lateral wall trochlea	medial wall trochlea	medial wall trochlea	most or all of trochlea
Carrying angle of elbow	decreased (<12°)	increased (>12°)	increased (>12°)	increased (>12°)	decreased (<12°)	decreased (<12°)
Deformity of elbow	cubitus varus	cubitus valgus	cubitus valgus	cubitus valgus	cubitus varus	cubitus varus
Treatment	(1) abduction (2) Kirschner wire (3) mid flexion forearm	(1) adduction (2) Kirschner wire (3) extension forearm	(1) adduction (2) new Kirschner wire old transpositional angulational osteotomy (3) mid flexion forearm	(1) adduction (2) Kirschner wire (3) mid flexion forearm	(1) abduction (2) Kirschner wire (3) extension forearm	(1) abduction (2) new Kirschner wire old transpositional angulational osteotomy (3) mid flexion forearm

FIG 214 Cubitus varus following Type 1 adduction fracture of the medial condyle The trochlear fragment has been completely resected leading to a fixed cubitus varus This should be corrected by simple wedge osteotomy

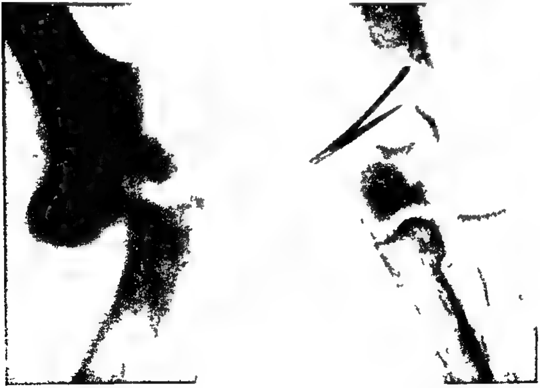


FIG 215 Type 2 adduction fracture dislocation of the medial condyle The trochlear surface has been dislocated into the joint space and there is medial dislocation of the forearm (*left*) Following open reduction and Kirschner wire pinning of the fractured trochlea anatomical restoration has been achieved (*right*) (Courtesy of Dr D Raskind)

TABLE 4.—SUMMARY OF CONDYLAR FRACTURES OF THE HUMERUS

	Lateral condyle			Medial condyle		
Direction of fracturing force	adduction (vs. lateral side)	upward along radius	upward along ulna	abduction (vs. medial side)	upward along radius	upward along ulna
Type of fracture	adduction fracture	Type 1 abduction fracture	Type 2 abduction fracture dislocation	abduction fracture	Type 1 adduction fracture	Type 2 adduction fracture-dislocation
Direction of fracture line	Laterally above to medially below			Medially above to laterally below		
Relation of fracture line to Trochlear groove	lateral	lateral	through or medial	through or medial	through or medial	through or lateral
Epicondylo trochlear sulcus	through or medial	through or medial	medial	medial	medial	through or medial
Displacement of condylar fragment	downward	upward	upward	downward	upward	upward
Composition of condylar fragment	capitellum + part lateral wall trochlea	capitellum + part lateral wall trochlea	capitellum + entire lateral wall trochlea	medial wall trochlea	medial wall trochlea	most or all of trochlea
Carrying angle of elbow	decreased ($<12°$)	increased ($>12°$)	increased ($>12°$)	increased ($>12°$)	decreased ($<12°$)	decreased ($<12°$)
Deformity of elbow	cubitus varus	cubitus valgus	cubitus valgus	cubitus valgus	cubitus varus	cubitus varus
Treatment	(1) abduction (2) Kirschner wire (3) mid flexion forearm	(1) adduction (2) Kirschner wire (3) extension forearm	(1) adduction (2) new: Kirschner wire; old: transpositional angulational osteotomy (3) mid flexion forearm	(1) adduction (2) Kirschner wire (3) mid flexion forearm	(1) abduction (2) Kirschner wire (3) extension forearm	(1) abduction (2) new: Kirschner wire; old: transpositional angulational osteotomy (3) mid flexion forearm

FRACTURES OF THE ULNA

FRACTURES OF THE UPPER END OF THE ULNA

While lateral or medial dislocations in the coronal plane result more commonly from fractures of the lower end of the humerus, anteroposterior dislocations in the sagittal plane are more common as the consequence of the fractures of the olecranon and coronoid processes of the ulna When the elbow is viewed from its medial aspect, it will be seen that the greater sigmoid cavity of the ulna subtends an arc of about one hundred and sixty degrees and embraces a correspondingly large segment of the articular surface of the trochlea (Fig 216) The upward projection of the olecranon prevents forward dislocation of the forearm in extension and the additional forward projection of its terminal beak acts to prevent forward dislocation of the elbow even in flexion In a similar manner, the forward and upward projection of the coronoid process serves to hinder backward dislocation of the elbow Reduction in extent of the circumferential arc of the sigmoid to below one hundred sixty degrees or loss of the upward projections of the olecranon and coronoid processes above the level of the articular surface of the humerus predisposes to dislocation either in the anterior or posterior directions (Fig 217)

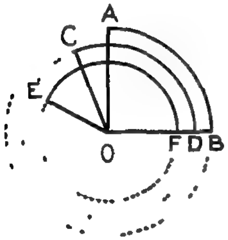


FIG 216 Arcs subtended by the greater sigmoid notch The angle *EOF* normally about one hundred sixty degrees represents the arc subtended by the normal sigmoid notch Angles of lesser magnitude tend to lead to anterior or posterior dislocations of the forearm at the elbow joint Although the arc *AB* is equal in length to the arc *CD* the likelihood of dislocation is greater in the former than in the latter since the angle *AOB* is less than the angle *COD* (Reproduced from Milch H Bilateral recurrent dislocation of the ulna at the elbow *J Bone & Joint Surg 18* 777 1936)

FRACTURES OF THE CORONOID PROCESS

Fracture of the coronoid process may result from muscle pull or from direct violence against the beak of the coronoid The significance of the coronoid process in backward dislocations is illustrated both by the occurrence of such dislocations following fractures of the process (Figs 218 and 219) and the possibility of preventing dislocation by bone graft reconstruction where the process has failed to develop normally (Fig 220) Although the fractured fragment is relatively small and buried deeply in the soft tissues, its replacement is essential to the prevention

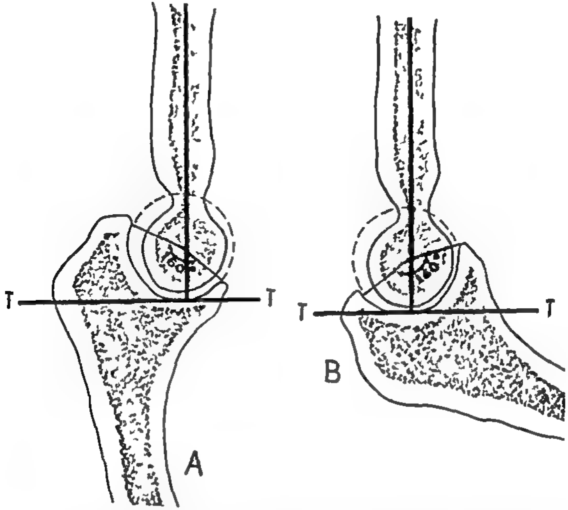


FIG 217 Sagittal view of the elbow In extension *A* anterior displacement may occur if fracture of the olecranon process occurs at or below the line *TT* which is tangent to the inferior articular surface and perpendicular to the longitudinal axis of the humerus Posterior dislocation of the ulna will result if fracture of the coronoid process occurs at or below the line *TT* In flexion *B* anterior dislocation of the ulna will occur following fracture of the olecranon process at or below the line *TT* while posterior dislocation will occur if fracture of the coronoid process occurs at or below the line *TT*

of backward dislocation of the ulna and to the avoidance of limitation of flexion of the elbow that invariably occurs if the displacement is not overcome This can be accomplished simply by acute flexion of the elbow and immobilization either on a posterior splint or by a figure of-eight plaster bandage in the Jones position (Fig 221) This maneuver serves to reduce the separation by compression of the fragment between the mass of the brachialis anticus muscle and the depths of the coronoid fossa Flexion should not be carried beyond a point compatible with the preservation of the circulation to the hand and fingers Despite the potential circulatory hazards of this position it is the only means whereby closed reduction of these fractures may be accomplished

FRACTURES OF THE ULNA

FRACTURES OF THE UPPER END OF THE ULNA

While lateral or medial dislocations in the coronal plane result more commonly from fractures of the lower end of the humerus, anteroposterior dislocations in the sagittal plane are more common as the consequence of the fractures of the olecranon and coronoid processes of the ulna When the elbow is viewed from its medial aspect, it will be seen that the greater sigmoid cavity of the ulna subtends an arc of about one hundred and sixty degrees and embraces a correspondingly large segment of the articular surface of the trochlea (Fig. 216) The upward pro-

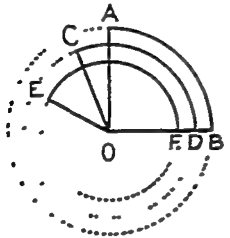


FIG 216 Arcs subtended by the greater sigmoid notch. The angle *EOF* normally about one hundred sixty degrees represents the arc subtended by the normal sigmoid notch. Angles of lesser magnitude tend to lead to anterior or posterior dislocations of the forearm at the elbow joint. Although the arc *AB* is equal in length to the arc *CD* the likelihood of dislocation is greater in the former than in the latter since the angle *AOB* is less than the angle *COD* (Reproduced from Milch, H., Bilateral recurrent dislocation of the ulna at the elbow *J Bone & Joint Surg 18* 777 1936)

jection of the olecranon prevents forward dislocation of the forearm in extension and the additional forward projection of its terminal beak acts to prevent forward dislocation of the elbow even in flexion. In a similar manner the forward and upward projection of the coronoid process serves to hinder backward dislocation of the elbow Reduction in extent of the circumferential arc of the sigmoid to below one hundred sixty degrees or loss of the upward projections of the olecranon and coronoid processes above the level of the articular surface of the humerus predisposes to dislocation either in the anterior or posterior directions (Fig. 217)

FRACTURES OF THE CORONOID PROCESS

Fracture of the coronoid process may result from muscle pull or from direct violence against the beak of the coronoid The significance of the coronoid process in backward dislocations is illustrated both by the occurrence of such dislocations following fractures of the process (Figs 218 and 219) and the possibility of preventing dislocation by bone graft reconstruction where the process has failed to develop normally (Fig. 220) Although the fractured fragment is relatively small and buried deeply in the soft tissues its replacement is essential to the prevention

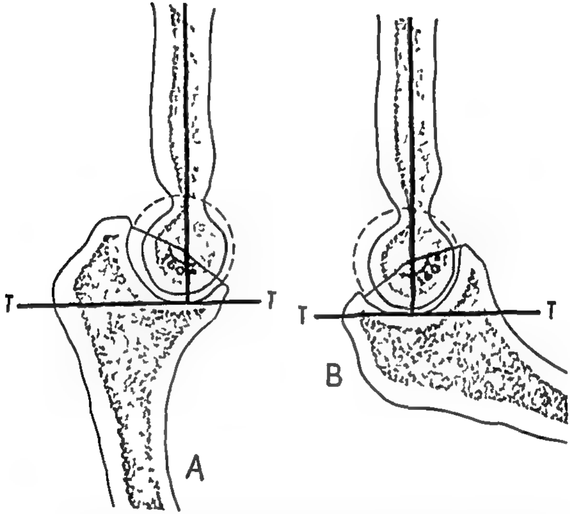


Fig 217 Sagittal view of the elbow In extension, *A*, anterior displacement may occur if fracture of the olecranon process occurs at or below the line *TT* which is tangent to the inferior articular surface and perpendicular to the longitudinal axis of the humerus Posterior dislocation of the ulna will result if fracture of the coronoid process occurs at or below the line *TT* In flexion *B* anterior dislocation of the ulna will occur following fracture of the olecranon process at or below the line *TT* while posterior dislocation will occur if fracture of the coronoid process occurs at or below the line *TT*

of backward dislocation of the ulna and to the avoidance of limitation of flexion of the elbow that invariably occurs if the displacement is not overcome This can be accomplished simply by acute flexion of the elbow and immobilization either on a posterior splint or by a figure of eight plaster bandage in the Jones position (Fig 221) This maneuver serves to reduce the separation by compression of the fragment between the mass of the brachialis anticus muscle and the depths of the coronoid fossa Flexion should not be carried beyond a point compatible with the preservation of the circulation to the hand and fingers Despite the potential circulatory hazards of this position, it is the only means whereby closed reduction of these fractures may be accomplished

FIG 218 Fracture of the coronoid process The coronoid process is fractured and displaced forward The upper end of the ulna is subluxated posteriorly with the fore arm in extension

FRACTURES OF THE OLECRANON PROCESS

Fracture of the olecranon process may occur at any point between its tip and the base of the lesser sigmoid notch of the ulna The most probable if not the sole cause of simple fractures is the pull of the triceps muscle Where the fracture line occurs at a point above the level of the horizontal portion of the ulnar sigmoid notch so that a portion of the olecranon remains as a bone block to prevent forward dislocation of the ulna the olecranon fragment may be treated conservatively (Figs 222 and 223) or may be removed with impunity (Fig 224)

Where the fracture occurs below the line tangent to the inferior articular surface of the humerus, resection of the fractured olecranon process is not permissible Before the development of adequate means of skeletal fixation fractures of the

FIG 219 Fracture of the coronoid process The coronoid process of the ulna has been fractured and displaced forward with the elbow in flexion The ulna is dislocated posteriorly There is early callus formation in malposition and subperiosteal new bone formation along the posterior aspect of the humerus obstructing extension and reduction

FIG 220 Congenital dislocation of the ulna Posterior ulnar dislocation resulted from failure of the coronoid beak to develop (*left*) This was corrected by implantation of a bone graft into the base of the coronoid process (*right*) (Reproduced from Milch H, Bilateral recurrent dislocation of the ulna at the elbow *J Bone & Joint Surg 18* 777, 1936)

Fig 218 Fracture of the coronoid process *The coronoid process is fractured* and displaced forward The upper end of the ulna is subluxated posteriorly with the fore arm in extension

Fractures of the Olecranon Process

Fracture of the olecranon process may occur at any point between its tip and the base of the lesser sigmoid notch of the ulna The most probable if not the sole cause of simple fractures is the pull of the triceps muscle Where the fracture line occurs at a point above the level of the horizontal portion of the ulnar sigmoid notch so that a portion of the olecranon remains as a bone block to prevent forward dislocation of the ulna, the olecranon fragment may be treated conservatively (Figs 222 and 223) or may be removed with impunity (Fig 224)

Where the fracture occurs below the line tangent to the inferior articular surface of the humerus resection of the fractured olecranon process is not permissible Before the development of adequate means of skeletal fixation, fractures of the

FIG 223 Old avulsion fracture of the posterior cortex of the olecranon process The anterior portion of the olecranon was not affected and the patient was simply immobilized in a splint until symptoms disappeared

olecranon were treated in complete extension of the forearm This released the pull of the triceps muscle and, at the same time, tended to align the olecranon process so as to avoid angulation and limitation of extension of the forearm The objection to this procedure was that it frequently resulted in limitation of flexion and tended to lead to arthritis of the elbow joint because of excessive callus formation at the line of fracture This has been largely overcome by the use of skeletal fixation devices If the fractured fragment consists of a single piece of bone, this may be fixed to the shaft of the ulna either by a Steinmann nail or a screw (Fig 225) If on the other hand, the fragment is markedly comminuted so that there is no purchase for an internal fixation device, the arm must be held in extension until sufficient healing has taken place to permit gradual attempts at flexion of the elbow

Fractures of the Upper End of the Radius

Force transmitted along the shaft of the radius may lead to fracture of the radial head in adults and to fracture of the radial neck in children Fractures of the radial head may vary from simple fissure fractures, without displacement, to comminuted fractures involving the entire head and even the neck Simple fissure fractures need be immobilized for only a short time until subsidence of pain permits motion of the elbow (Fig 226) More severe injuries result in depression of

FIG 221 Healed fracture of the coronoid process This fracture was treated in the Jones position The original fracture line can still be visualized Healing has occurred with slight forward displacement of the process but the arc of the sigmoid notch has been restored and backward dislocation of the upper end of the ulna is prevented by the upward projection of the coronoid beak

FIG 222 Fracture of the tip of the olecranon process There is sufficient upward projection of the olecranon to prevent forward dislocation of the upper end of the ulna in both flexion and extension This patient was treated by simple immobilization in a right angle splint until the acute symptoms had subsided

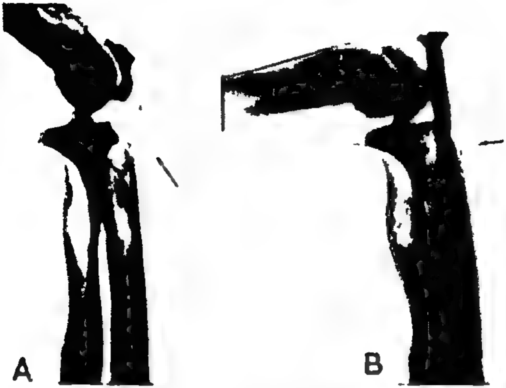


Fig 225 Fracture of the olecranon process below the critical tangent line There is wide separation of the fragment owing to the pull of the triceps muscle when the elbow is in flexion *A* A screw was inserted with the elbow in extension and thereafter immobilization was maintained in flexion *B*

Fig 226 Fissure fracture of the radial head There is a small fissure fracture involving the anterolateral portion of the circumference of the radial head There is no displacement and immobilization needs to be continued until the acute symptoms have subsided

FIG 224 Fracture of the olecranon process above the critical tangent line The small stump of the olecranon base is sufficient to prevent forward dislocation of the ulna (*left*) The fragment was resected with ultimate new bone formation in the lower end of the triceps tendon (*right*)

various parts of the circular radial head If the depressed fragment lies in the outer portion of the circumference of the head where it does not interfere with rotation of the forearm surgery is not indicated (Fig 227) If in adults, however, the fragment lies in that portion of the arc of rotation of the radius where it impairs motion it should be removed at open operation (Fig 228)

The radial head can be removed through a posterolateral incision made from the external epicondyle down to the level of the radial neck with the elbow in flexion The incision is carried down to the level of the radiohumeral joint which is opened exposing the radial head Care should be taken to smooth off the upper end of the radial shaft and if possible to cover its bare area with soft tissue so as to avoid the chance of subsequent outgrowth of osteophytes that may cause painful limitation of motion If the resection is strictly limited to the region of the head there is no danger of injury to the posterior interosseous nerve that passes

forward around the neck of the radius After removal of the head, the orbicular ligament is sutured The forearm is immobilized for several days until the postoperative response has subsided, after which guarded active motion may be begun

Some surgeons have advised waiting for a period of about ten days before undertaking resection of the radial head in the belief that earlier intervention tends to increase the danger of myositis ossificans Little is known of the cause of either myositis ossificans or of calcification of hematomata, which seems to occur with greater likelihood after injuries about the elbow joint than elsewhere in the body

FIG 229 Comminuted fracture of the radial head and neck There was marked limitation of motion and at open operation a large fragment was found to have been displaced upward into the elbow joint (*left*) The fragments were resected with almost complete restoration of elbow function (*right*)

It seems highly probable, however, that these occurrences are due to causes other than the surgical intervention, and cases have been repeatedly operated upon shortly after injury without the development of this undesired ossification It is, of course, desirable to avoid unnecessary trauma to the surrounding musculature by approaching the area through the relatively free zone behind the extensor muscles of the forearm

Where there is a fracture of the radial head associated with a fracture of the radial neck it is probably best to remove the radial head (Fig 229) Similarly, in those rare cases where there is a combined fracture of the capitellum humeri and a fracture of the radius with impaction of the capitellar fragment into the radial head, it is best to excise the radial head (Fig 230)

Fig 227 Fracture of the radial head Depressed fracture of the anterior and lateral portions of the radial head There was no limitation of pronation or supination Surgical intervention therefore was not indicated

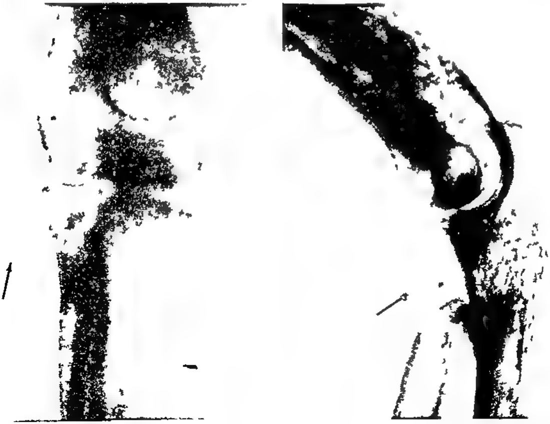


Fig 228 Comminuted fracture of the radial head and neck Following removal of the comminuted fragments new bone formation occurred in the site of the surgical defect but without limitation of motion (*right*)

In children removal of the radial head should be avoided, since it may lead to an upward shifting of the entire radius with disruption of the inferior radioulnar joint. Where the fracture is through the radial neck, but bony contact has been maintained so that only the plane of the articular surface is altered, an effort should be made to improve the position by angulating the forearm medially and pushing the radial head into better position. Where the head is completely severed from the shaft, so that its fractured surface lies against the shaft of the bone, closed manipulation is not likely to succeed and open operation for replacement of the radial head on the shaft of the radius is indicated. This should be carried out with great gentleness and as soon as the diagnosis is established (Fig. 231). Delay of several weeks adds immeasurably to the difficulty of reduction. To prevent displacement of the radial head after reduction, the elbow should be flexed and held in that position while the skin wound is being closed. This position should be maintained for at least four weeks, after which gradual motion may be instituted.

Fig 230 Fracture of the capitellum humeri and the capitellum radii There was no motion at the elbow joint and at open operation a stellate fracture of the radial head was found with the fragment of the capitellum humeri inserted between the radial head fragments (Reproduced from Milch H Unusual fractures of the capitellum humeri and the capitellum radii *J Bone & Joint Surg* *13* 882 1931)

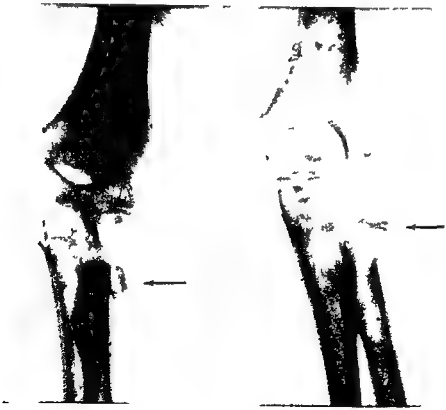


Fig 231 Fracture of the radial neck in a child The radial head has been completely displaced so that the fractured surface is parallel to the shaft of the radius (*left*) Closed manipulation was unavailing and operative replacement of the radial head was undertaken (*right*)

In children, removal of the radial head should be avoided, since it may lead to an upward shifting of the entire radius with disruption of the inferior radioulnar joint Where the fracture is through the radial neck, but bony contact has been maintained so that only the plane of the articular surface is altered an effort should be made to improve the position by angulating the forearm medially and pushing the radial head into better position Where the head is completely severed from the shaft, so that its fractured surface lies against the shaft of the bone, closed manipulation is not likely to succeed and open operation for replacement of the radial head on the shaft of the radius is indicated This should be carried out with great gentleness and as soon as the diagnosis is established (Fig 231) Delay of several weeks adds immeasurably to the difficulty of reduction To prevent displacement of the radial head after reduction, the elbow should be flexed and held in that position while the skin wound is being closed This position should be maintained for at least four weeks after which gradual motion may be instituted

Fig 230 Fracture of the capitellum humeri and the capitellum radii There was no motion at the elbow joint and at open operation a stellate fracture of the radial head was found with the fragment of the capitellum humeri inserted between the radial head fragments (Reproduced from Milch H Unusual fractures of the capitellum humeri and the capitellum radii *J Bone & Joint Surg* *13* 882 1931)

Fig 231 Fracture of the radial neck in a child The radial head has been completely displaced so that the fractured surface is parallel to the shaft of the radius (*left*) Closed manipulation was unavailing and operative replacement of the radial head was undertaken (*right*)

Immobilization should be continued for a period of at least six months before a definite diagnosis of nonunion can be established When this occurs, operative intervention, preferably using an onlay type of bone graft must be undertaken

When displacements occur, the direction of the displacement is almost solely dependent upon the direction of the fracturing force The most significant dis-

FIG 233 Fracture of the ulnar shaft Oblique fracture of the upper end of the ulna treated by wiring (*left*) Union was complete with slight posterior bowing of the shaft of the bone in five weeks (*right*)

placement that may occur is one resulting from outward angulation at the site of the fracture This may interfere with the rotatory movements of the radius and must be avoided If the fracture occurs in the middle of the shaft of the ulna, it is sometimes possible to reduce the fragments by causing a posterior bowing so that the surgeon s fingers may be inserted into the interosseous space to force the fragments inward Once this has been accomplished and end to-end apposition of the fragments obtained the posterior bowing can be readily corrected to assure proper alignment Where this is impossible, correction may occasionally be obtained by

CHAPTER 15

Fractures of the Forearm

FRACTURES OF THE SHAFT OF THE ULNA

Fracture of the ulna alone usually results from direct trauma. In cases where there is no displacement, simple immobilization in a full-arm plaster of Paris cast extending from the proximal palmar crease to the mid arm, with the elbow in right-

FIG 232 Fracture of the ulnar shaft. Transverse fracture of the lower third of the ulna (*left*). After immobilization for a period of three months there is evidence of delayed union with slight malalignment (*right*). This fracture ultimately healed completely.

angled flexion, usually results in sound healing after four to six weeks. Delayed union and nonunion, however, are not at all infrequent and immobilization must be continued until there is evidence either of healing or of frank nonunion (Fig 232).

Immobilization should be continued for a period of at least six months before a definite diagnosis of nonunion can be established When this occurs operative intervention, preferably using an onlay type of bone graft must be undertaken

When displacements occur, the direction of the displacement is almost solely dependent upon the direction of the fracturing force The most significant dis-

FIG 233 Fracture of the ulnar shaft Oblique fracture of the upper end of the ulna treated by wiring (*left*) Union was complete with slight posterior bowing of the shaft of the bone in five weeks (*right*)

placement that may occur is one resulting from outward angulation at the site of the fracture This may interfere with the rotatory movements of the radius and must be avoided If the fracture occurs in the middle of the shaft of the ulna, it is sometimes possible to reduce the fragments by causing a posterior bowing so that the surgeon s fingers may be inserted into the interosseous space to force the fragments inward Once this has been accomplished and end to end apposition of the fragments obtained the posterior bowing can be readily corrected to assure proper alignment Where this is impossible, correction may occasionally be obtained by

CHAPTER 15

Fractures of the Forearm

Fractures of the Shaft of the Ulna

Fracture of the ulna alone usually results from direct trauma In cases where there is no displacement simple immobilization in a full-arm plaster of Paris cast extending from the proximal palmar crease to the mid-arm, with the elbow in right-

Fig 232 Fracture of the ulnar shaft Transverse fracture of the lower third of the ulna (*left*) After immobilization for a period of three months there is evidence of delayed union with slight malalignment (*right*) This fracture ultimately healed completely

angled flexion usually results in sound healing after four to six weeks Delayed union and nonunion however are not at all infrequent and immobilization must be continued until there is evidence either of healing or of frank nonunion (Fig 232)

be described the *flexion type* in which the distal ulnar fragment is displaced anteriorly with posterior angulation between the two fragments and an *extension type* in which the distal fragment of the ulna is displaced posteriorly with anterior angulation between the two fragments In either event the radial head may be dislocated either anteriorly or posteriorly (Figs 235 and 236) The extension type is

Fig 235 Monteggia s fracture anterior displacement of radial head The distal fragment of the ulnar shaft is displaced anteriorly and the radial head is dislocated anteriorly (*left*) After reduction and fixation of the ulnar fragments by a Lane type of bone plate it was noted that there was a small lip fracture of the radial head (*right*) The latter caused no difficulty and no particular attention was directed to its care

seen more commonly than the flexion type It has been claimed by some that closed reduction is possible in both of these fracture types Owing to the difficulty in maintaining the position of the fractured ulnar fragments, however, *it is not unlikely* that the poor results that have been observed in Monteggia s fractures are the results of efforts at closed reduction Open reduction and internal fixation appear to be the procedure of choice

The fracture of the ulna should always be treated first It frequently happens that the dislocation of the radial head can be corrected without difficulty as soon

inserting two Kirschner wires through the interosseous membrane close to the fractured ulna or actually into the bone fragments themselves for the purpose of exerting an inward force to overcome the outward angulation

Where the fracture occurs proximal to the mid shaft and where control of the proximal fragment accordingly, is more difficult, it is probably wiser to undertake open, operative reduction Since healing in the ulna is usually a slow process firm

Fig 234 Fracture of the ulnar shaft Transverse fracture of the upper end of the ulna treated by bone plating with excellent anatomical alignment

fixation of the fracture either by a wire metallic plate, or an intramedullary pin usually offers better prospects for successful maintenance of the reduction than can be obtained either by metallic bands or by simple bone suture (Figs 233 and 234)

Monteggia s Fracture

Fracture of the ulnar shaft is frequently observed in association with other injuries especially with fracture of the radius in the form described by Monteggia

Monteggia s fracture is a fracture of the upper third of the ulna with a dislocation or a fracture dislocation of the radial head Two types of this fracture may

Fractures of the Lower End of the Ulna

Isolated fractures of the lower end of the ulna are extremely rare (Fig 237) Fractures in this region are usually associated with fractures elsewhere in the forearm bones Fracture of the ulnar styloid process is almost constantly associated with Colles fracture and does not require special attention, even though nonunion occasionally occurs Where isolated sprain fracture occurs, the hand should be immobilized in the position of function and in ulnar deviation Excision of small nonunited fragments should be avoided if at all possible since it leads to weakness

Fig 237 Isolated fracture of the ulnar styloid process Longitudinal fracture of the lower end of the ulnar styloid with slight displacement of the fragment The fracture healed uneventfully following simple plaster of Paris cast immobilization

of the wrist through loss of the insertion of the ulnar collateral ligament Before resorting to this extreme measure injections of local anesthetics should be performed in an effort to control persistent pain

Fractures of Both Bones of the Forearm

Fractures of both bones of the forearm are fairly common and result usually from a fall on the outstretched hand or from a direct blow They most frequently involve the middle and lower thirds of the forearm (Fig 238)

Occasionally, when the fracture lines are transverse, it is possible to reduce these fractures by engaging one of the bones end-to end and then using this as a lever to realign the other bone (Fig 239) More satisfactory results, however will usually be achieved by the judicious use of traction With the patient under anesthesia, the arm is held flat against the table while the elbow is flexed to a right angle Gentle traction is then applied to the distal part of the forearm and the ends of both bones are molded into end-to end apposition Care should be taken to avoid torsion of the distal fragments during the manipulative procedure while traction

as the length of the ulna has been restored If this does not occur, the radial head can be exposed through a separate incision either for repair of the inevitably torn orbicular ligament or for the removal of any fragments of the radial head that may have been displaced during the act of dislocation Following the reduction the

FIG 236 Monteggia s fracture posterior displacement of radius In this less common flexion type of Monteggia s fracture the distal ulnar fragment is displaced anteriorly and angulated posteriorly but the radial head is dislocated posteriorly (*left*) After open reduction and internal fixation of the ulnar shaft fracture a lip fracture of the radial head was discovered and the intraarticular fragment was removed (*right*)

forearm should be immobilized in a long arm cast in the position of mid flexion for six weeks The flexed position avoids the dangers of stiffness and limitation of elbow joint motion that the necessary position of extension would impose following *attempts* at closed reduction

Fractures of the Lower End of the Ulna

Isolated fractures of the lower end of the ulna are extremely rare (Fig 237) Fractures in this region are usually associated with fractures elsewhere in the forearm bones Fracture of the ulnar styloid process is almost constantly associated with Colles fracture and does not require special attention even though nonunion occasionally occurs Where isolated sprain fracture occurs, the hand should be immobilized in the position of function and in ulnar deviation Excision of small nonunited fragments should be avoided if at all possible since it leads to weakness

Fig 237 Isolated fracture of the ulnar styloid process Longitudinal fracture of the lower end of the ulnar styloid with slight displacement of the fragment The fracture healed uneventfully following simple plaster of Paris cast immobilization

of the wrist through loss of the insertion of the ulnar collateral ligament Before resorting to this extreme measure injections of local anesthetics should be performed in an effort to control persistent pain

Fractures of Both Bones of the Forearm

Fractures of both bones of the forearm are fairly common and result usually from a fall on the outstretched hand or from a direct blow They most frequently involve the middle and lower thirds of the forearm (Fig 238)

Occasionally when the fracture lines are transverse, it is possible to reduce these fractures by engaging one of the bones end-to end and then using this as a lever to realign the other bone (Fig 239) More satisfactory results, however, will usually be achieved by the judicious use of traction With the patient under anesthesia the arm is held flat against the table while the elbow is flexed to a right angle Gentle traction is then applied to the distal part of the forearm and the ends of both bones are molded into end-to end apposition Care should be taken to avoid torsion of the distal fragments during the manipulative procedure while traction

FIG 238 Fracture of both bones of fore arm Satisfactory alignment of mid shaft fractures of both bones has been achieved by traction The forearm was immobilized in a plaster cast and healing was uneventful

on the forearm is maintained A light plaster splint is applied immobilizing both the elbow and wrist joints After this has set a circular plaster bandage is applied from above the elbow to the level of the proximal palmar crease X-rays should be made immediately to exclude the possibility of any torsional malalignment If any exists the reduction must be corrected and it is, therefore, wise to apply only a few turns of the plaster bandage and then to check the position of the fragments by fluoroscopy or roentgenography In the absence of any unreduced malalignment the plaster bandage can then be completed incorporating a metallic marker in the cast (Fig 73) The cast should remain in place until there is evidence of firm union usually four to six weeks

It is particularly in this type of fracture that the roentgenogram can be most deceptive What may appear to be increasing displacement of the fragments may be due to nothing more than a difference in the projection at which the x-ray was taken *No conclusion should or indeed can be drawn unless there is absolute* assurance that the roentgenographic exposures have been made in exactly the same position as at the time of the original reduction (Figs 24 25, and 26)

Fractures of both bones in the upper third of the forearm are less common than in the middle and lower third are often characterized by marked comminution, and usually result from severe injuries (Fig 240) Where possible, these fractures should be treated by skeletal fixation Properly employed intramedullary nails afford an excellent method of avoiding narrowing of the interosseous space with the danger of cross union (Fig 241), as well as a relatively easy means of reducing an apparently severe fracture

In instances where internal skeletal fixation is impossible, however, molding of the fractured fragments should be attempted and the forearm should be im-

FIG 239 Fracture of both bones of forearm Reduction of lower third fractures of both bones of the forearm has been accomplished by end to end apposition of the ulna and then by levering the radius into position (*right*)

mobilized in the semiflexed position This represents a position of function for the elbow joint should ankylosis supervene Such treatment is not ideal, but it does have the merit of obviating the frequently more serious dangers attendant upon ill advised surgical intervention Despite the most distressing appearance of the roentgenogram, the range of motion after healing may be far greater than could have been anticipated on the basis of the x-ray appearance

Fractures in the lower third in children are apt to be of the green stick variety When the axial malalignment is of mild degree no effort at reduction need be made since angulation of less than twenty-five degrees will usually be corrected during the normal growth of the bone Angulations of greater than this degree are probably best corrected by gentle pressure care being exercised to avoid converting a

FIG 238 Fracture of both bones of fore arm Satisfactory alignment of mid shaft fractures of both bones has been achieved by traction The forearm was immobilized in a plaster cast and healing was uneventful

on the forearm is maintained A light plaster splint is applied immobilizing both the elbow and wrist joints After this has set a circular plaster bandage is applied from above the elbow to the level of the proximal palmar crease X-rays should be made immediately to exclude the possibility of any torsional malalignment If any exists the reduction must be corrected and it is, therefore, wise to apply only a few turns of the plaster bandage and then to check the position of the fragments by fluoroscopy or roentgenography In the absence of any unreduced malalignment the plaster bandage can then be completed incorporating a metallic marker in the cast (Fig 73) The cast should remain in place until there is evidence of firm union, usually four to six weeks

It is particularly in this type of fracture that the roentgenogram can be most deceptive What may appear to be increasing displacement of the fragments may be due to nothing more than a difference in the projection at which the x ray was taken No conclusion should or indeed can be drawn unless there is absolute assurance that the roentgenographic exposures have been made in exactly the same position as at the time of the original reduction (Figs 24 25 and 26)

FIG 241 Fracture of both bones of forearm This fracture was improperly treated and cross union resulted from the fact that torsion persisted after attempted reduction It is evident that the upper half of the film presents an anteroposterior view of the forearm bones while the lower half presents the normal lateral view of the fore arm

green-stick into a complete type of fracture (Fig 242) If, however, satisfactory correction is impossible by this method conversion of the green-stick fracture into a complete fracture by manipulation is justifiable and will frequently permit satisfactory axial realignment

In children operation should be avoided provided that end to-end apposition can be attained Generally speaking, it is possible to secure adequate alignment by fixation of one of the bones If this happens to be the bone with the transverse fracture line the reduction may be stable If however, the fracture line is oblique

Fig 240 Fracture of both bones of forearm Comminuted fractures of the upper thirds of the radius and ulna as well as a fracture of the lower end of the ulna (*left*) treated by intra medullary pin fixation with satisfactory end result (*right*) (Courtesy of Dr B Kleiger)

FIG 241 Fracture of both bones of forearm This fracture was improperly treated and cross union resulted from the fact that torsion persisted after attempted reduction It is evident that the upper half of the film presents an anteroposterior view of the forearm bones while the lower half presents the normal lateral view of the fore arm

green stick into a complete type of fracture (Fig 242) If, however, satisfactory correction is impossible by this method, conversion of the green stick fracture into a complete fracture by manipulation is justifiable and will frequently permit satisfactory axial realignment

In children operation should be avoided provided that end-to-end apposition can be attained Generally speaking, it is possible to secure adequate alignment by fixation of one of the bones If this happens to be the bone with the transverse fracture line, the reduction may be stable If however, the fracture line is oblique

FIG 240 Fracture of both bones of forearm Comminuted fractures of the upper thirds of the radius and ulna as well as a fracture of the lower end of the ulna (*left*) treated by intra medullary pin fixation with satisfactory end result (*right*) (Courtesy of Dr B Kleiger)

FIG 243 Fracture of both bones of the forearm in an adolescent Repeated attempts at closed reduction were unsuccessful because of the instability of the ulnar fracture (*left*) Following skeletal fixation of the ulna the radius was easily aligned and maintained in position (*right*)

FRACTURES OF THE LOWER END OF THE RADIUS

Fractures of the lower end of the radius are the most common of radial fractures and among the most common of all fractures In children, the fall upon the outstretched hand, which in adults produces one or another of the types of Colles' fractures, may result in epiphyseal separation (Figs 246, 247, and 248), in a torus type of fracture (Fig 249) or in a transverse fracture of the lower end of the bone (Fig 250) Where displacement is minimal or absent simple immobilization in a forearm cast in the position of function (about thirty degrees dorsal extension of the wrist) for a period of four to six weeks usually suffices to assure healing Where there is displacement the distal fragment must be aligned with the proximal and the treatment is essentially the same as that of a Colles' fracture in the adult In children immobilization may be continued for a longer period of time without fear of stiffness of the wrist or fingers than is possible in adults

Epiphyseal separations should be treated as simple fractures The patient s family should be warned of the possibility of impairment of growth especially where the force has been such as to compress the epiphyseal plate While a simple

FIG 242 Fracture of both bones of the fore arm in a child There is a green stick fracture of the lower end of the ulna and a torus fracture of the lower end of the radius (*left*) These were corrected by angulation of the distal forearm without creating a complete fracture of either of the bones (*right*)

in both bones and the resulting reduction is unstable, it may be necessary to undertake skeletal fixation for one or both bones (Fig 243)

FRACTURES OF THE SHAFT OF THE RADIUS

Isolated fractures of the upper and middle portions of the radius are less common than those of the ulna Displacement may vary somewhat, depending upon the direction of the fracturing force and the location of the fracture The general tendency is for the fracture site to angulate medially under the influence of the pronator teres muscle acting on the upper fragment and the pronator quadratus muscle acting upon the lower fragment The appearance of angulation however may also be caused by torsion of the distal fragment and realignment, in this event, may be accomplished by simply derotating the fragment (Fig 244) Usually it is possible to maintain the reduction that has been obtained by simple cast immobilization Where this is impossible immobilization by wiring or plating is justified (Fig 245)

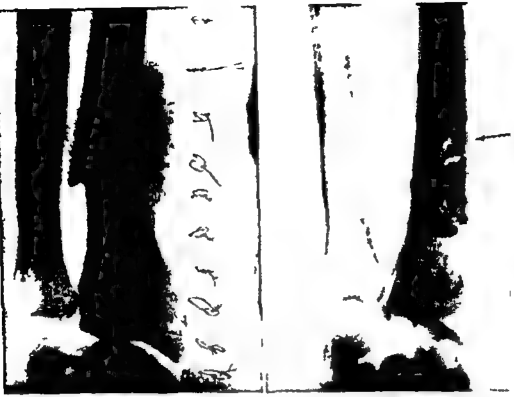


FIG 245 Fracture of the radial shaft There is lateral displacement at the line of fracture (*left*) Although satisfactory reduction could be easily obtained the reduced position could not be maintained until after skeletal fixation by a metallic plate was accomplished (*right*)

FIG 246 Epiphyseal separation of the lower end of the radius There is posterior displacement of the distal radial epiphysis No treatment other than simple immobilization until pain had subsided was indicated here

FIG 244 Fracture of the radial shaft There is torsion of the distal fragment as is evidenced by the antero posterior appearance of the upper end of the radius and the lateral appearance of the lower end (*left*) Reduction and alignment were accomplished by simple supination of the distal fragment (*right*)

shearing off of the epiphyseal plate may result in interference in growth, the likelihood of this complication is less than after compressive injuries The result of compression of the inferior radial epiphysis is premature ossification of the epiphysis with overgrowth of the ulna leading to radial deviation of the hand (Figs 251, 252 and 253)

Several different methods have been devised for correcting the unaesthetic appearance of the wrist after this complication Resection of the lower end of the ulna (Darrach operation) is not to be recommended because it may lead to weakening

FIG 248 Epiphyseal separation of the lower end of the radius The epiphyseal separation seen in Fig 247 could be easily reduced but could not be maintained until fixed in the Cotton Loder position as in the treatment of Colles fracture

that a typical Colles fracture may and commonly does present all four of the axial malalignments that a fractured bone can manifest The *first* of these is a transpositional malalignment in which the distal fragment is translated backwards, leading to a prominence of the dorsum of the hand that is one component of the characteristic silver fork deformity (*dorsal transposition*) (Fig 256) The *second* is angulational and is due to a rotation of the distal fragment around a transverse axis so that the normal volar direction of the inferior articular surface is converted to a dorsal

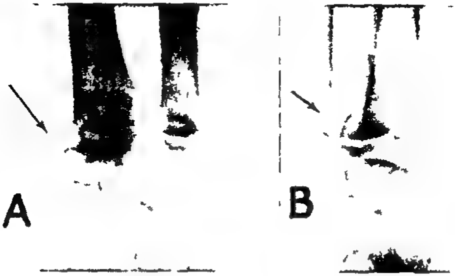


FIG 247 Epiphyseal separation of the lower end of the radius There is a postero lateral displacement of the distal radial epiphysis *A*, with fractures of the posterior lip of the radius and ulna *B*

of the wrist through loss of the ulnar collateral ligaments or broadening of the wrist with deformation of the lower end of the ulna (Fig 254) The cuff resection operation (Fig 255) has the advantage of preserving the integrity of the ulnar collateral ligaments, while restoring the normal disparity in length between the radius and the ulna without widening of the wrist

COLLES FRACTURE

In the adult fractures of the lower end of the radius are usually designated as Colles fractures This is not literally true since other forms of fracture at the lower end of the radius, including Smith s fracture, Barton s fracture and fracture of the radial styloid process have been described separately

Although Colles described a fracture that takes place within an inch and a half above the carpal extremity of the radius, the modern concept of Colles fracture includes only those fractures that occur within three quarters of an inch of the lower end of the radius The distal fragment by definition, is always either dorsally transposed or dorsally angulated and is usually associated with a fracture of the ulnar styloid process Originally, Colles fracture was mistaken for a dislocation of the carpus and it was Pouteau who first described the true nature of the condition in 1783 Despite this accurate appreciation of the fracture and its subsequent description by Colles in 1814 it was not until much later that the knowledge became generally accepted Since that time, much has been written on the subject of this fracture but it is still not generally understood and the results of its treatment leave much to be desired

Part of the difficulty may arise from the improper emphasis that has been placed on one of the deformities the so-called silver fork deformity to the exclusion of other malalignments that are actually more important It is essential to remember

FIG 248 Epiphyseal separation of the lower end of the radius The epiphyseal separation seen in Fig 247 could be easily reduced but could not be maintained until fixed in the Cotton Loder position, as in the treatment of Colles fracture

that a typical Colles fracture may and commonly does present all four of the axial malalignments that a fractured bone can manifest The *first* of these is a transpositional malalignment in which the distal fragment is translated backwards, leading to a prominence of the dorsum of the hand that is one component of the characteristic silver fork deformity (*dorsal transposition*) (Fig 256) The *second* is angulational and is due to a rotation of the distal fragment around a transverse axis so that the normal volar direction of the inferior articular surface is converted to a dorsal

FIG 249 Torus fracture of the lower radial shaft This simple buckling fracture was of insufficient degree to warrant any treatment other than simple immobilization to control pain

FIG 250 Fracture lower end of radius Complete transverse impacted fracture of the lower radius slightly above the level of the true Colles fracture with minimal dorsal angulation of the distal fragment Immobilized for control of pain

Fig 251 Compression of the inferior radial epiphysis There is narrowing and sclerosis of the medial half of the radial epiphysis indicative of a compressive type of injury It is this type of epiphyseal trauma that specifically leads to growth impairment

Fig 252 Old compression of the inferior radial epiphysis As a child the patient fell headlong from a tree landing on his outstretched hands Premature closure of the radial epiphysis with overgrowth of the ulna ensued Apart from this unaesthetic deformity there was no impairment of function (Reproduced from Milch H Bilateral post traumatic ulno cuneiform articulation *Am J Roentgenol* 60 80 1949)

direction (*dorsal angulation*) (Fig 257) The *third* is a torsional malalignment resulting from rotation of the distal fragment in relation to the proximal portion of the bone (*supination*) (Fig 258) The *fourth* is of a lineal nature and is due to impaction of the distal into the proximal fragment so that the radius is shortened and the radial styloid comes to lie proximal to its normal position (*short radius*) (Fig 259)

The silver fork deformity may result from one or more of three distinct types of axial malalignment *A*, dorsal angulation, *B*, dorsal transposition, or *C* supination of the distal fragment (Fig 260) While dorsal angulation or dorsal transposition

FIG 249 Torus fracture of the lower radial shaft This simple buckling fracture was of insufficient degree to warrant any treatment *other than simple immobilization to control* pain

FIG 250 Fracture lower end of radius Complete transverse impacted fracture of the lower radius slightly above the level of the true Colles fracture with minimal dorsal angulation of the distal fragment Immobilized for control of pain

FIG 251 Compression of the inferior radial epiphysis There is narrowing and sclerosis of the medial half of the radial epiphysis indicative of a compressive type of injury It is this type of epiphyseal trauma that specifically leads to growth impairment

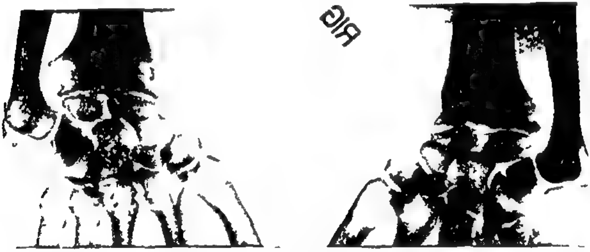


FIG 252 Old compression of the inferior radial epiphysis As a child the patient fell headlong from a tree landing on his outstretched hands Premature closure of the radial epiphysis with overgrowth of the ulna ensued Apart from this unaesthetic deformity there was no impairment of function (Reproduced from Milch H Bilateral post traumatic ulno-cuneiform articulation *Am J Roentgenol* *60* 80 1949)

direction (*dorsal angulation*) (Fig 257) The *third* is a torsional malalignment resulting from rotation of the distal fragment in relation to the proximal portion of the bone (*supination*) (Fig 258) The *fourth* is of a lineal nature and is due to impaction of the distal into the proximal fragment, so that the radius is shortened and the radial styloid comes to lie proximal to its normal position (*short radius*) (Fig 259)

The silver-fork deformity may result from one or more of three distinct types of axial malalignment *A* dorsal angulation, *B* dorsal transposition, or *C*, supination of the distal fragment (Fig 260) While dorsal angulation or dorsal transposition

Fig 253 Old compression of the inferior radial epiphysis Patient of Fig 252 There is radial deviation of both hands, but no limitation of either pronation or supination (Reproduced from Milch H Bilateral post traumatic ulno cuneiform articulation *Am J Roentgenol 60* 80 1949)

Fig 254 Old compression of the inferior radial epiphysis There has been overgrowth of the ulna with radial deviation of the hand Following resection of the lower end of the ulna the radial deviation of the hand has been corrected but in consequence there is an ulnar deviation of the regenerated lower end of the ulna with widening of the wrist and weakness of grasp in the hand (Reproduced from Milch H So-called dislocation of the lower end of the ulna *Ann Surg 116* 282 1942)

as well as lineal compression (telescoping) can be recognized in a segmental or a partial view of the lower end of the radius alone, torsional (supination) malalignment cannot be accurately diagnosed except on films taken to include the entire forearm *No film of any fracture at the lower end of the radius should be read unless it is a film that shows both the inferior and superior articular surfaces of both bones of the forearm*

Shortening of the radius and supination of the distal fragment are unequivocally the most important of the characteristic malalignments of Colles fractures Failure

FIG 255 Cuff resection of the ulna Abnormal disparity in length between the ulna and radius resulting from an old compressive injury to the inferior radial epiphysis has been corrected by cuff resection of the ulna (Reproduced from Milch H Cuff resection of the ulna *J Bone & Joint Surg* *23* 311 1941)

to correct torsion will result in a definite loss of the range of pronation of the forearm, while failure to correct shortening will result in a radial deviation and consequently a weakness of grasp in the hand Correction of these deformities, even to the exclusion of correction of the dorsal transposition and the dorsal angulation, is the prime therapeutic requirement for satisfactory outcome While an actual transpositional deformity is somewhat unaesthetic, owing to prominence of the lower end of the ulna it causes relatively little disability It is far less disturbing than dorsal angulation of the inferior articular surface, which may impair the degree of flexion of the wrist

Adequate reduction of a Colles' fracture implies correction of all the existing axial malalignments This can be accomplished under local anesthetics injected directly into the fracture hematoma, under brachial block anesthesia, or general anes-

FIG 253 Old compression of the inferior radial epiphysis Patient of Fig 252 There is radial deviation of both hands but no limitation of either pronation or supination (Reproduced from Milch H Bilateral post traumatic ulno cuneiform articulation *Am J Roentgenol 60* 80 1949)

FIG 254 Old compression of the inferior radial epiphysis There has been overgrowth of the ulna with radial deviation of the hand Following resection of the lower end of the ulna the radial deviation of the hand has been corrected but in consequence there is an ulnar deviation of the regenerated lower end of the ulna with widening of the wrist and weakness of grasp in the hand (Reproduced from Milch H So-called dislocation of the lower end of the ulna *Ann Surg 116* 282 1942)

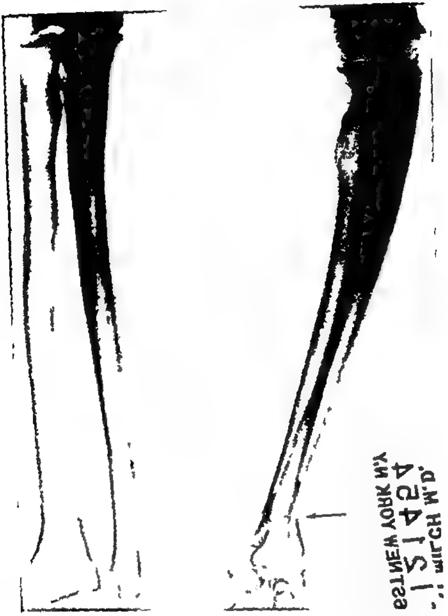


Fig 257 Healed Colles fracture Silver fork deformity owing almost entirely to dorsal angulation of the distal fragment

various maneuvers are most expeditiously performed under direct fluoroscopic visualization

Plaster immobilization involves the application of a cast extending from the metacarpophalangeal joints to the middle of the arm The cast should be carefully molded in the palm to preserve the normal hollow of the hand (Fig 87) A flat hand is worse by far than a flat foot since it impairs normal grasping power of the thumb The cast should be carefully trimmed so as to permit early motion of the fingers and apposition of the thumb The wrist should be held in the position in which reduction was accomplished, preferably in the Cotton Loder position, and the elbow should be flexed at a right angle (Fig 262) While immobilization of the elbow is theoretically proper and though it does relieve the patient of some pain

FIG 256 Colles fracture Silver fork deformity owing mainly to dorsal transposition of the distal fragment There is also a slight degree of dorsal angulation

thesia Where the distal fragment is intact, the impaction must first be thoroughly freed by traction and manipulation Once the distal fragment is freely mobile, it must be pronated while traction is maintained This in itself may be sufficient to effect adequate reduction of all the deformities, as well as specifically correcting the shortening of the radius and supination of the distal fragment If dorsal transposition still persists after these maneuvers the fragment may be displaced forward by the thumb of one hand while the wrist is brought into flexion by the surgeon's other hand, so as to correct the dorsal angulation This must be of sufficient degree to restore the normal angular relationship of the lower end of the radius to the axis of the shaft (approximately twelve degrees anterior angulation) To retain the lengthening of the radius the wrist is then adducted toward the ulnar side until the normal level of downward projection of the radial styloid (approximately 1 cm beyond the ulnar styloid) has been reached This involves placing the hand in the so called Cotton-Loder position (Fig 261) Before immobilization in this position the accurate correction of the various axial displacements must be checked by fluoroscopic or roentgenographic control Despite the dangers to the hands of the surgeon these

FIG 259 Colles fracture Shortening of the radius has occurred owing to impaction and telescoping of the distal into the proximal fragment

that otherwise is present during the first few days after reduction, a cast to below the elbow may be used without fear of losing position except in excessively stout extremities

In patients above the age of forty years, the extreme flexion of the wrist necessary to correct the dorsal angulation may lead to later inability to extend the wrist if immobilization is continued beyond two weeks Because the union at the site of fracture is not yet firm at this time, release from the position of volar flexion should be undertaken very gently while the wrist is being brought into the neutral position Thereafter the wrist may be gently moved at intervals with due regard to maintaining the position of the distal fragment while continuing immobilization on a volar splint for several weeks longer or until evidence of firm union has appeared

This type of treatment depends upon the integrity of the capsular apparatus for maintenance of position Where the distal fragment is severely comminuted and extensive laceration of the joint capsule may be predicated, manipulation of the nature just described is impossible In this event it is necessary to make traction on the patient s hand while the numerous pieces of distal fragment are molded into their relatively normal positions and are immobilized in a plaster cast (Figs 263 and 264) Where the stability of the reduction is uncertain and shortening is feared as a result of muscular pull the length of the radius may be maintained by passing a transfixing pin through one or more of the metacarpal bones and two other transfixing pins through the proximal radius These are incorporated either in the plaster cast or in one of the numerous forms of commercially available external immobilizing apparatus These wires should be removed after three to four weeks Despite

FIG 258 Colles fracture *A* silver fork deformity appears to result from a dorsal displacement of the distal fragment *B* silver fork deformity is seen to result from supination of the distal fragment This is the same photograph shown in *A* but here it can be recognized that the upper end presents its normal anteroposterior appearance while the lower end of the radius presents an oblique appearance owing to supination of the distal fragment

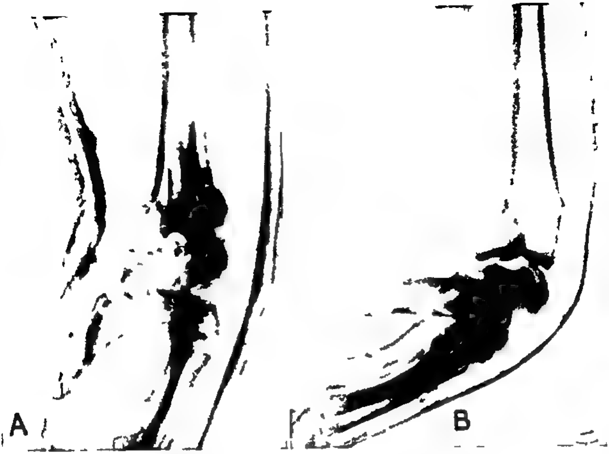


Fig 261 Immobilization of Colles fracture When immobilized in the neutral position dorsal transposition and dorsal angulation of the distal fragment still persist *A* Flexion of the wrist serves to correct these axial malalignments by making tension on the dorsal radiocarpal ligament Maintenance of the length of the radius by ulnar adduction of the wrist is achieved by making traction upon the radial collateral ligament of the wrist *B*

Fig 262 Cotton Loder position for immobilization of Colles fracture The wrist is in flexion and in ulnar adduction The plaster of Paris cast may extend above the elbow or may be shortened after several days to below the elbow

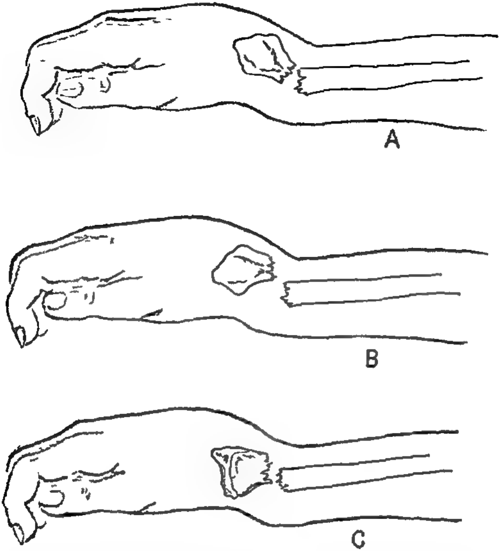


FIG 260 Silver fork deformity of Colles fracture due to *A* dorsal angulation *B* dorsal transposition and *C* supination of the distal fragment In *C* note anteroposterior appearance of distal radial fragment on lateral view of forearm

fair approximation of the fragments however, the outlook for return of function in these cases is necessarily less satisfactory than in other types of Colles' fracture where the articular surface is not so severely comminuted

In late cases where relative disparity in length between the radius and the ulna persists correction of the disabling radial deviation of the hand can be accomplished by a cuff resection of the ulna Since the lower end of the ulna is subcutaneous a Z type of osteotomy can be easily carried out with shortening of an inch or more Because of the danger of nonunion following osteotomy, the cut ends of the ulna should be fixed by a small four-screw plate (Fig 265) Correction of the other deformities dorsal angulation and dorsal transposition necessitates osteotomy of the lower end of the radius In some cases preliminary shortening of the ulna may be necessary

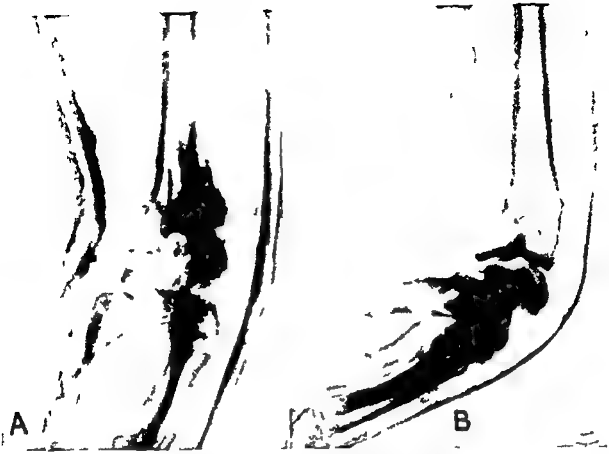


FIG 261 Immobilization of Colles fracture When immobilized in the neutral position dorsal transposition and dorsal angulation of the distal fragment still persist *A* Flexion of the wrist serves to correct these axial malalignments by making tension on the dorsal radiocarpal ligament Maintenance of the length of the radius by ulnar adduction of the wrist is achieved by making traction upon the radial collateral ligament of the wrist *B*

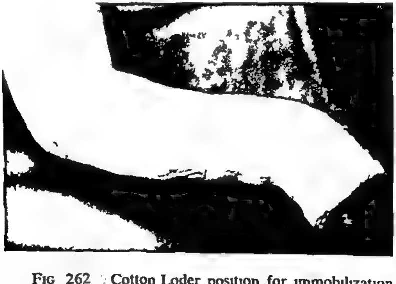


FIG 262 Cotton Loder position for immobilization of Colles fracture The wrist is in flexion and in ulnar adduction The plaster of Paris cast may extend above the elbow or may be shortened after several days to below the elbow

FIG 263 Comminuted Colles fracture There is involvement of the radiocarpal as well as the inferior radioulnar joints This patient was treated by cast immobilization with resulting marked limitation of motion

FIG 264 Comminuted Colles fracture in a child Despite involvement of the articular surface simple cast immobilization was followed by a satisfactory end result

FIG 265 Malunited Colles fracture Before osteotomy for correction of the radial deformities could be undertaken shortening of the ulna by cuff resection and fixation by a four screw Lane plate was necessary

The disability resulting from persistence of the torsional deformity is most difficult to correct Where an arthritis of the inferior radioulnar joint develops, resection of the lower end of the ulna is justified It should be remembered, however, that resection of the lower end of the ulna involves a sacrifice of the ulnar collateral ligament and the probability of weakening the wrist joint For this reason, resection of the ulna is carried out above the ulnar styloid process that is permitted to remain fixed to the carpus (Fig 266)

FIG 263 Comminuted Colles fracture There is involvement of the radiocarpal as well as the inferior radioulnar joints This patient was treated by cast immobilization with resulting marked limitation of motion

FIG 264 Comminuted Colles fracture in a child Despite involvement of the articular surface simple cast immobilization was followed by a satisfactory end result

Occasional complications of Colles' fractures are compression of the median nerve in the carpal canal, irritative phenomena related to the posterior interosseous nerve and, very rarely, a causalgia that may be most distressing Late rupture of the extensor pollicis longus tendon resulting from fraying as it passes over irregularities at the fracture site may also occur Actual disruption of the inferior radioulnar ligament

Fig 268 Smith's fracture So called reversed Colles fracture is characterized by volar angulation or volar transposition of the distal fragment (*left*) The essential of treatment is dorsal extension of the wrist (*right*)

ment with disparity in length of the ulna may give rise to any of the forms of so-called dislocation of the lower end of the ulna (Fig 267) There is, of course, no such condition as dislocation of the head of the ulna since in extension the position of the ulna is fixed at the elbow It is, rather, the radius with the attached carpus that is displaced

This situation is to be carefully differentiated from the so called dislocations of the ulnar head that are associated with no disparity in length between the ulna and the radius and in which the ligaments are stretched and not torn Where there is a

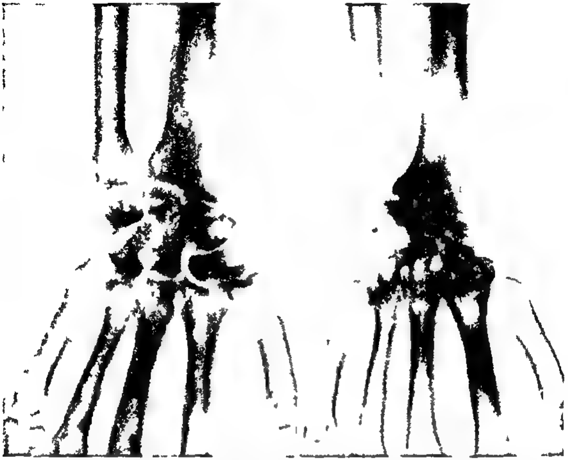


FIG 266 Osteoarthritis following Colles fracture There was marked limitation of pronation and supination with pain on flexion and extension of the wrist An arthrodesis of the wrist was undertaken to overcome pain (*left*) Pseudarthrosis by cuff resection of the ulna leaving the lower end of the ulna to maintain stability of the wrist was performed (*right*)

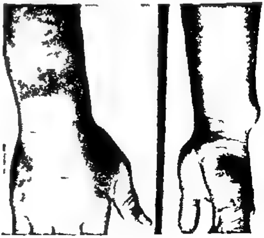


FIG 267 So called dislocation of the ulnar head The head of the ulna becomes *prominent on pronation* of the wrist but it is actually the carpus that is displaced

sum of the volar flexed hand and may present all the other axial deformities characteristics of Colles' fracture Reduction is carried out in essentially the same manner after freeing of the impaction by manipulation, save that the distal fragment must ultimately be dorsiflexed rather than volar flexed as in Colles' fracture After careful attention to the correction of any torsional malalignment, the distal fragment should be maintained in dorsiflexion and ulnar deviation (Fig 268)

Barton's Fracture

Barton's fracture, an isolated fracture of the posterior margin of the lower end of the radius, is frequently overlooked Its importance lies in the fact that the posterior margin of the lower end of the radius forms the base for the grooves through

Fig 270 Fracture of the anterior lip of the radius There is upward and forward displacement of the anterior lip of the radius (Courtesy of Dr H Seidenstein)

which the extensor tendons of the fingers glide Any irregularity in these osseous canals may lead to attrition of the tendons and ultimate subcutaneous rupture This is not uncommon after Colles fracture and involves particularly the extensor pollicis longus tendon

In children Barton's type of fracture may appear in the form of a posterior luxation of the distal radial epiphysis (Fig 269) These fractures or radial separations must be treated exactly as the typical Colles fracture and, after reduction, should be immobilized in the Cotton-Loder position

Fractures of the Anterior Lip of the Radius

Fracture of the anterior lip of the lower end of the radius is an *extremely unusual* fracture It results from a fall upon the hand with the wrist in slight flexion

Fig 269 Barton s fracture Fracture of the dorsal lip of the lower end of the radius in this case associated with slight posterior displacement of the lower radial epiphysis and a very mild torus compression of the ulna

true lateral separation between the inferior ends of the radius and ulna, reconstruction of the inferior radioulnar ligaments by means of a fascial graft is indicated Where there is merely disparity in length shortening of the ulna by cuff resection suffices to cure the so-called dislocation

Smith s Fracture

A reversed Colles fracture in which the distal fragment is transposed or angulated anteriorly, is called Smith s fracture It usually results from a fall on the dor-

give rise to little or no disability (Fig. 272). These should be protected in the neutral position by a light plaster of Paris cast extending from the metacarpophalangeal joints to below the elbow until healing has occurred, usually within three to four weeks. Where the fracture is more comminuted and the fracture line enters the articular surface, the prognosis must be more guarded and treatment should, in general, be identical with that given to Colles' fractures.

FIG. 273. Chauffeur's fracture. Isolated fracture of the radial styloid process. There was very little displacement and treatment was by simple immobilization in the neutral position. The outcome was satisfactory despite involvement of the articular surface. (Anteroposterior and lateral views.)

Fractures of the Radial Styloid

Isolated fracture of the radial styloid process, the so-called chauffeur's fracture, is a relatively rare lesion that was more commonly seen before self-starters were made standard equipment on automobiles. It usually results from the impaction of the carpal scaphoid bone against the articular surface of the radial styloid. Where there is no displacement, immobilization of the wrist in the neutral position for a period of about four weeks usually suffices to assure bony healing (Fig. 273). Where there is displacement this can usually be corrected by manipulation and the hand should then be immobilized in the position in which reduction was effected, for a period of about four weeks.

and may be termed a reversed Barton's fracture (Fig 270) Retention is difficult and may necessitate skeletal traction through the metacarpals (Fig 271)

Longitudinal Fractures of the Lower Radius

Longitudinal fractures at the lower end of the radius arise in consequence of falls on the outstretched hand Simple linear fractures with but little displacement

Fig 271 Fractures of the anterior lip of the radius Reduction could be obtained without difficulty but the position could not be maintained until skeletal traction through Kirschner wires inserted into metacarpal bones had been fixed in the encircling plaster of Paris cast (Courtesy of Dr H Seidenstein)

Fig 272 Longitudinal fracture of the lower end of the radius This fracture arose in consequence of a fall upon the outstretched hand and was treated by simple immobilization in the neutral position

Fig 275 Fracture of the scaphoid and fracture of the radial styloid process The fracture line through the waist of the scaphoid appears as a dark line resulting from impaction of the fragments There is bone resorption along the line of fracture The vertical fracture of the radial styloid process can be seen in good position

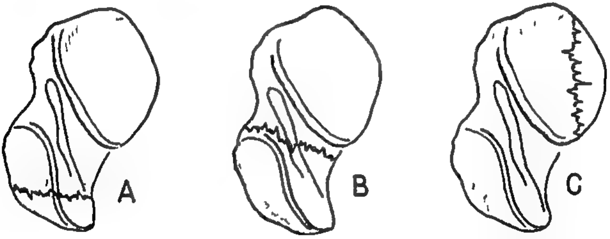


Fig 276 Fractures of the scaphoid In *A* there is a fracture of the tuberosity These fractures usually heal without difficulty if adequately immobilized In *B*, there is a fracture through the waist which is the most common type of scaphoid fracture These usually heal if immobilized for a sufficient length of time Nonunion and aseptic necrosis however may occur in the proximal fragment In *C* there is a fracture of the proximal pole Necrosis in this region is very common

CHAPTER 16

Fractures of the Carpus

Fractures of each of the carpal bones have been reported By all means the most common, however, is fracture of the carpal scaphoid This fracture is frequently seen in association with Colles' fracture (Fig 274), or fractures of the radial *styloid process (Fig 275) With the exception of the pisiform, which has been frac*

FIG 274 Fracture of the scaphoid and Colles fracture Fracture of the scaphoid has occurred through the waist of the bone and is impacted The Colles fracture is in good position

tured in consequence of excessive pull of the flexor carpi ulnaris muscle, all the other carpal fractures have been reported to arise from direct blows or falls upon the hand

FRACTURES OF THE SCAPHOID

The carpal scaphoid (navicular) may be fractured in any of three different sites the distal tuberosity *A* the waist *B*, or the proximal pole, *C* (Fig 276) *Fractures of the distal tuberosity are usually well vascularized and heal without any*

FIG 275 Fracture of the scaphoid and fracture of the radial styloid process The fracture line through the waist of the scaphoid appears as a dark line resulting from impaction of the fragments There is bone resorption along the line of fracture The vertical fracture of the radial styloid process can be seen in good position

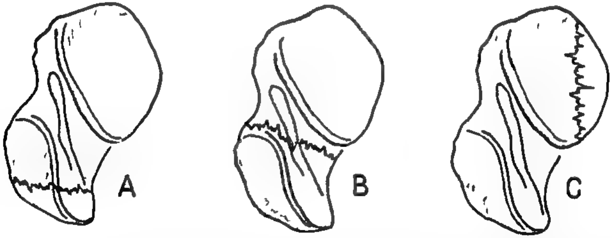


FIG 276 Fractures of the scaphoid In *A* there is a fracture of the tuberosity These fractures usually heal without difficulty if adequately immobilized In *B* there is a fracture through the waist which is the most common type of scaphoid fracture These usually heal if immobilized for a sufficient length of time Nonunion and aseptic necrosis however may occur in the proximal fragment In *C* there is a fracture of the proximal pole Necrosis in this region is very common

difficulty under simple plaster of Paris cast immobilization Fractures of the waist and proximal pole, on the other hand, present an entirely different problem and, unless properly treated, may result in a high percentage of aseptic necrosis and nonunion (Fig 277) This may be due to two mechanisms (1) the fracture line is completely intraarticular and hence is poorly vascularized, and (2) the scaphoid straddles the carpus with its proximal pole in the upper row of carpal bones while its distal pole lies in the distal row, so that even slight motion between the two rows of the carpal bones interferes with the normal processes of healing

FIG 277 Old fracture of the carpal scaphoid Aseptic necrosis of both the proximal and distal poles of the scaphoid following a fracture through the upper pole of the bone Nonunion at the fracture line is indicated by the tip of the arrow

Clinically fracture of the scaphoid may be suspected in the presence of pain localized to the area of the anatomical snuffbox Roentgenographically, acute fractures of the scaphoid are frequently not clearly visualized in routine anteroposterior views of the wrist In doubtful cases it is important to take oblique views of the carpus, preferably with the wrist in ulnar adduction Occasionally, even such views fail to disclose the fracture which may become apparent only a week or two after the injury when bone resorption at the fracture line has occurred

Treatment of the acute fracture should be conservative If properly immobilized for a sufficient length of time a minimum of ten to twelve weeks, most of the fractures through the waist of the scaphoid will heal Fractures through the proximal

pole take longer, are frequently followed by aseptic necrosis, and heal only by a process of creeping substitution

Immobilization should be by means of a snugly fitting plaster of Paris cast, the scaphoid cast (Fig 278) This differs from the ordinary cockup plaster of Paris wrist cast in that the thumb as well as the wrist must be immobilized The wrist should be held in about thirty degrees of dorsal extension and preferably in radial deviation, with the thumb in the position of hand function The cast should immobilize the metacarpal of the thumb and at least the proximal phalanx of the thumb

Fig 278 The scaphoid cast The cast extends from well up on the forearm to the distal palmar crease The wrist is held in slight dorsal extension with radial deviation of the hand The thumb is immobilized in a position of opposition down to at least the interphalangeal joint

It should be only lightly padded and should be well molded into the palm so as to preserve the hollow of the hand In the hand, the cast should not extend below the proximal transverse crease of the palm Above, it must extend well up on the forearm

At the end of ten to twelve weeks the cast should be removed for the purpose of making x-ray views, which should be taken in the standard as well as in oblique positions Unless there is definite evidence of bone union across the fracture line a new cast should be applied and left in place for another ten to twelve weeks If at the end of this time there is evidence of early union, still a third cast should be applied If however there is definite evidence of nonunion the question of further treatment must be faced

Not every case of nonunion needs surgical intervention Surgical treatment is indicated only in those cases in which there is persistence of disability and pain

There is much difference of opinion as to the nature of the surgical procedure that is indicated In the presence of simple symptomatic nonunion, the fragments may be drilled so as to open new channels for vascularization A small bone graft may be placed across the fracture line to splint the fragments and afford a bridge along which new bone growth can occur Where there is pain, without evidence of arthritis in the radiocarpal joint, fusion of the two rows of carpal bones to the fractured fragments of the scaphoid may lead to subsidence of symptoms without loss of wrist joint motion Where there is evidence of arthritis in the wrist joint, however, radiocarpal fusion is indicated (Fig 279)

FIG 279 Arthritis of the radiocarpal joint following scaphoid fracture There is an old fracture of the wrist of the scaphoid with displacement of the fragments and narrowing of the radiocarpal joint Fusion of the wrist joint was undertaken

Excision of the entire scaphoid leads to a marked shifting of the position of the other carpal bones and a serious loss of all motions of the wrist To prevent this, some have advised the insertion of an artificial scaphoid and others have recommended proximal carpectomy This is indicated, however, only in very extreme cases associated with intolerable pain

In those cases of nonunion in which there are no symptoms of pain or disability and in which the fractured scaphoid presents the character of a bipartite scaphoid no treatment is indicated (Fig 280)

FRACTURES OF THE HAMATE

Fractures of the hamate may occur through the body of the bone or through the hamular process Fracture of the body may occur medial to the hamular proc-

Fig 280 Nonunited fracture of the scaphoid The fracture through the waist is still visualized The patient however complained of no symptoms and presented no disability No further treatment was indicated

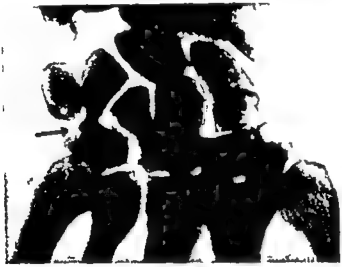


Fig 281 Fracture of the hamate Recent fracture of the hamate with moderate separation of the fragments The fracture line characteristically extends from above and medially to below and laterally Union did not occur in this case but the patient presented no subsequent symptoms of pain or disability (Reproduced from Milch H Fracture of the hamate bone *J Bone & Joint Surg* *16* 459 1934)

ess but is most frequently lateral to this process (Fig 281) The line of fracture is from above and medial to below and lateral Displacement is usually slight, but may be complete Except roentgenographically, it is impossible to differentiate between fractures of the body and the hamular process Treatment is by immobilization in a plaster of Paris cast in the cockup position and healing has been reported within six weeks This is not an invariable outcome, however, and nonunion may occur In itself nonunion is no indication for further treatment Where pain and disability persist particularly of the wrist operative fusion of the fragments should

be undertaken provided that the fragments are viable Where a fragment is necrotic, this should be removed

Fractures of the Capitate

Fractures of the capitate, though unusual, may be particularly disabling because the capitate bone is the keystone of the carpus and involves both the proximal and distal row of carpal bones Fractures occur more commonly through the neck of the bone, displacement is slight, and healing usually occurs within six to eight weeks

FIG 282 Fracture of the capitate Fracture has occurred through the waist of the bone with dorsal displacement of the proximal fragment

under proper immobilization in a short-arm cast (Fig 282) Traumatic arthritis of the surrounding joints may lead to considerable pain and limitation of motion

Sprain Fractures of the Carpus

Sprain fractures are probably more frequent than the frank fractures of any of the carpal bones (Fig 283) These are frequently diagnosed as simple sprains which should be suspect in the presence of persistent pain and disability of the wrist The most common of these is that involving the cuneiform (triquetrum) Lying as it does in the proximal row of the carpus a fall on the hyperextended hand leads to compression of the bone between the lower end of the ulna and the pisiform and a consequent flaking of the dorsal surface of the bone (Fig 284) This fracture may appear as an isolated injury or in association with other fractures notably of the ulna (Fig 285)

FIG 283 Compression fracture of the lunate A small depression is present on the proximal articular surface of the lunate and a small free fragment of bone is present in the joint space

FIG 284 Sprain fracture of the cuneiform A small portion of bone has been flaked off the dorsal surface of the bone

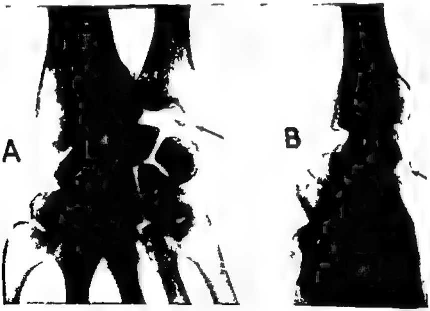


FIG 285 Sprain fracture of the cuneiform (triquetrum) A small flake from the dorsal surface of the cuneiform is present on the lateral view B This is associated with a fracture of the ulnar styloid process A

In addition to the usual signs of pain, swelling, and local tenderness, there is but little on which the diagnosis can be made except the roentgenogram On the normal anteroposterior views, such x-rays may be completely negative for evidence of fracture It is essential that oblique films in several different positions be made Treatment is completely conservative Immobilization in a cockup splint or a plaster of Paris cast for a period of three to four weeks, followed by physiotherapy, usually results in subsidence of symptoms

CHAPTER 17

Fractures of the Hand

Fractures of the metacarpals and phalanges are very common and, unless properly and promptly treated, may lead to unsightly and disabling deformities Dysfunction may arise from (1) angulation of the bone, with loss of the mechanical efficiency of the overlying tendons, (2) adhesions of the tendons lying in juxtaposition to the injured bone, and (3) capsular contracture or arthritic involvement of the carpometacarpal, metacarpophalangeal, or the interphalangeal joints

FRACTURES OF THE METACARPALS

Fractures of the metacarpals may involve the shaft or either extremity of the bone They usually arise in consequence of direct blows or falls upon the hand The base of the thumb metacarpal and the distal extremity of the metacarpal of the little finger appear to be the sites of most frequent fracture

Fractures of the Proximal Portion of the Metacarpals

Fractures at the base of the second to the fifth metacarpals usually result in only slight displacement In most instances, they heal uneventfully and require nothing more than immobilization on a dorsal splint or over a bandage roll fixed in the hollow of the hand so as to allow of some motion at the interphalangeal joints Healing is however, not invariable and delayed union or nonunion may occur In the latter event, open operation and fixation by a small intramedullary bone graft may be necessary

Fractures at the base of the thumb present a special problem because of the extreme mobility of this so called metacarpal bone Where the other carpometacarpal joints are of the simple gliding type, which permit limited motion, the thumb joint is somewhat saddle-shaped and permits the variety of motions that has been said to characterize the ascent of man in the evolutionary scale

Two types of fractures have been described in this area Rolando s fracture and Bennett s fracture (Fig 286)

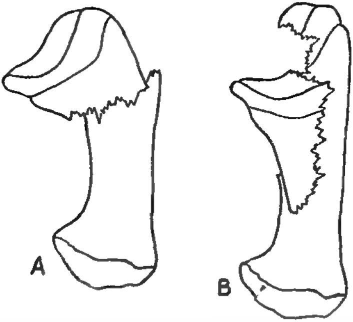


FIG 286 Fractures at the base of the thumb *A* Rolando s fracture This is a fracture of the upper end of the metacarpal shaft in which the hook of the base is preserved *B*, Bennett s fracture This is a fracture of the base entering the carpometacarpal joint *where the beak is fractured and the metacarpal* shaft is displaced upward

FIG 287 Rolando s fracture The fracture line is transverse and distal to the hook at the base of the metacarpal There is no upward dislocation of the metacarpal shaft and healing occurred after immobilization in a plaster of Paris cast that included the thumb in the position of function of the hand

Rolando s fracture is a fracture through the neck of the bone just distal to the articular surface It may be comminuted, though it is usually transverse and does not involve the hooklike projection of the medial portion of the base of the bone As a consequence there is no tendency toward upward displacement of the shaft of the thumb metacarpal and alignment either by abduction of the distal fragment of

the bone or by axial traction is sufficient to secure adequate replacement and union at the site of fracture (Fig 287)

Bennett s fracture is of an entirely different nature It is primarily a fracture of the medially projecting lip of the base of the bone, rather than of the base as a whole This triangular medial fragment remains locked between the base of the index finger metacarpal and the greater multangular bone, while the main portion of the metacarpal of the thumb is displaced upward and outward (Fig 288) Simple abduction does not suffice to realign the fragments and reduction of the fracture is

FIG 288 Bennett s fracture The fracture line passes obliquely through the base of the hook of the metacarpal and there is upward displacement of the metacarpal shaft

possible only by a force radially directed to counteract the distorting action of the long thumb muscles This can be accomplished only by direct traction either through the finger pulp or through the distal end of the metacarpal bone Traction is obtained by attaching the traction loops over a wire incorporated in a small plaster of Paris spica that includes the wrist, hand, and the thumb metacarpal Traction must be maintained for a period of at least four weeks and immobilization should not be discontinued until there is assurance of firm bony union (Fig 289)

If the position of the fragments cannot be maintained by this type of traction, open reduction and pinning of the fragment to the body of the bone is essential to restoration of thumb function (Fig 290) In old cases, where nonunion has occurred with the shaft of the bone displaced proximally, open operation for replacement and skeletal fixation of the fragment or abduction osteotomy at the base of the bone to reconstruct the restraining action of the hook is indicated

FIG 289 Bennett s fracture Traction must be applied to the shaft in order to pull it distally and to realign it with the hook of the metacarpal which remains fixed between the greater multangular and the base of the index metacarpal

FIG 290 Bennett s fracture Upward displacement was prevented by Kirschner wire fixation of the metacarpal to the carpus

Epiphyseal Separation of the Base of the Thumb

Epiphyseal separation at the base of the thumb is unusual It resembles the Rolando type of fracture in the adult The fracture line is transverse to the long axis of the metacarpal and reduction can be accomplished by manipulation (Fig 291)

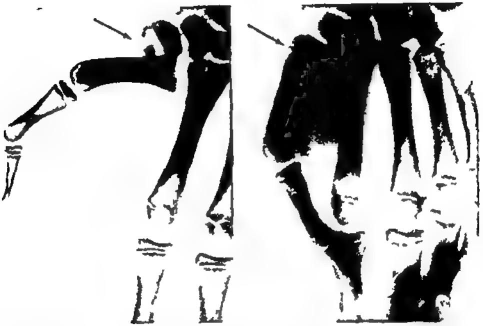


Fig 291 Epiphyseal separation at the base of the thumb In abduction there is marked separation of the fragment (*left*) This is overcome with excellent reduction of the fracture when the thumb is brought into adduction (*right*)

Fractures of the Shaft of the Metacarpals

Fractures of the shaft of the metacarpal bones may be either transverse or spiral The spiral fractures usually show little displacement (Fig 292), but the transverse fractures are almost constantly characterized by dorsal angulation at the site of fracture with volar displacement of the distal fragment owing to the action of the interosseous muscles (Fig 293) In consequence of this deformity, the action of the extensor muscle is impaired, while the palmar projection of the metacarpal head impairs the normal power of grasp in the hand Maintenance of the normal curve of the metacarpal bones is extremely important and the casual application of an immobilizing dorsal splint may serve to convert the normal dorsal curve into a volar angulation with loss of bony contact and ultimate nonunion of the fracture

If the dorsal angulation is minimal, simple immobilization on a dorsal splint or over a bandage roll may be employed in the absence of more suitable dorsal splints (Fig 294) Immobilization on a bandage roll however, should not be employed for more than two to three weeks Maceration of the skin and stiffness of the fingers is almost constantly associated with this method and the loss of finger mobility may prove more distressing than the original malalignment

FIG 289 Bennett's fracture Traction must be applied to the shaft in order to pull it distally and to realign it with the hook of the metacarpal which remains fixed between the greater multangular and the base of the index metacarpal

FIG 290 Bennett's fracture Upward displacement was prevented by Kirschner wire fixation of the metacarpal to the carpus

Epiphyseal Separation of the Base of the Thumb

Epiphyseal separation at the base of the thumb is unusual It resembles the Rolando type of fracture in the adult The fracture line is transverse to the long axis of the metacarpal and reduction can be accomplished by manipulation (Fig 291)

Fig 291 Epiphyseal separation at the base of the thumb In abduction there is marked separation of the fragment (*left*) This is overcome with excellent reduction of the fracture when the thumb is brought into adduction (*right*)

Fractures of the Shaft of the Metacarpals

Fractures of the shaft of the metacarpal bones may be either transverse or spiral The spiral fractures usually show little displacement (Fig 292), but the transverse fractures are almost constantly characterized by dorsal angulation at the site of fracture with volar displacement of the distal fragment owing to the action of the interosseous muscles (Fig 293) In consequence of this deformity, the action of the extensor muscle is impaired, while the palmar projection of the metacarpal head impairs the normal power of grasp in the hand Maintenance of the normal curve of the metacarpal bones is extremely important and the casual application of an immobilizing dorsal splint may serve to convert the normal dorsal curve into a volar angulation with loss of bony contact and ultimate nonunion of the fracture

If the dorsal angulation is minimal, simple immobilization on a dorsal splint or over a bandage roll may be employed in the absence of more suitable dorsal splints (Fig 294) Immobilization on a bandage roll, however should not be employed for more than two to three weeks Maceration of the skin and stiffness of the fingers is almost constantly associated with this method and the loss of finger mobility may prove more distressing than the original malalignment

FIG 289 Bennett's fracture Traction must be applied to the shaft in order to pull it distally and to realign it with the hook of the metacarpal which remains fixed between the greater multangular and the base of the index metacarpal

FIG 290 Bennett's fracture Upward displacement was prevented by Kirschner wire fixation of the metacarpal to the carpus

Where the dorsal angulation exceeds ten to fifteen degrees, there is no alternative to adequate correction of the malalignment by surgical intervention If the fracture is simple and occurs through the mid shaft, intramedullary fixation appears to be the method of choice, since it barely interferes with motion of the fingers A heavy Kirschner wire, inserted from the distal or proximal end of the bone, is driven across the fracture line into the other fragment Though it has been asserted that this wire may be introduced across the articular cartilage without danger of stiffness of the involved joint, it is unquestionably better to avoid this potential source

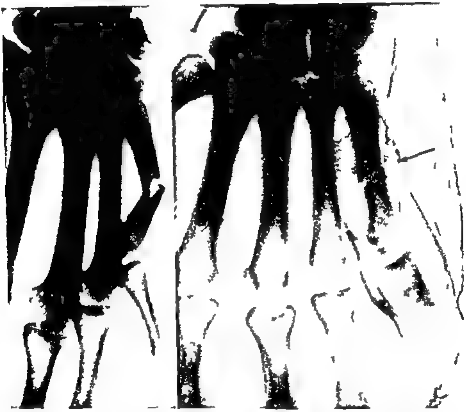


FIG 294 Fracture of the metacarpal shaft The characteristic dorsal angulation (*left*) has been overcome by the application of a dorsal splint which fixes not only the distal fragment but also the proximal phalanx (*right*)

of danger and to insert the wire through a small drill hole near but not through the cartilaginous surface One end of the wire may be left subcutaneous for subsequent withdrawal, or it may be buried in the bone and left permanently As a matter of precaution and to facilitate withdrawal of the wire in the event of infection or other untoward accident, the former procedure is preferable (Fig 295)

An alternative method of treatment is fixation by transcortical Kirschner wires inserted so that they penetrate the cortex of the adjacent metacarpal bone that acts as an additional means of alignment The pins are left protruding through the skin and are incorporated in the light, short forearm cast that is applied following reduction They should be left in situ until there is evidence of adequate healing of the fracture (Fig 296)

FIG 292 Spiral fracture of the metacarpal shaft There is but little displacement and union occurred after immobilization on a dorsal splint

FIG 293 Fracture of the metacarpal shaft Simple wiring was ineffective in preventing the characteristic dorsal angulation resulting from the action of the interosseous muscles (Courtesy of Dr J William Littler)

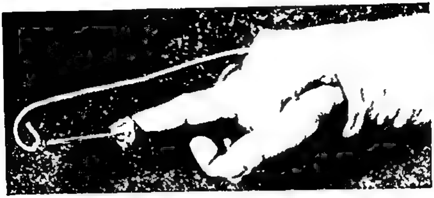


FIG 297 Traction for metacarpal fracture A small needle has been passed through the pulp of the distal phalanx and traction has been applied through the intermediation of a Granberry bow attached over the end of a long wire incorporated in a short forearm cast

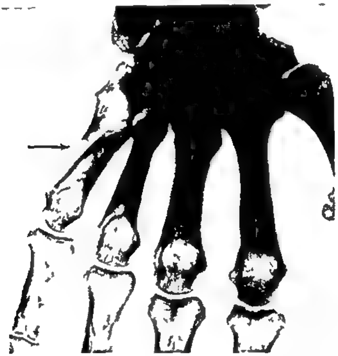


FIG 298 Spiral fracture of metacarpal shaft of fifth finger Delayed union occurred after eight weeks immobilization Union ultimately occurred after a further period of immobilization

If the fracture is comminuted or occurs through the distal end of the bone so that intramedullary fixation is either impossible or undesirable, traction must be employed Traction may be exerted through adhesive tape strips attached to the fingers or by small metal pins inserted into the pulp of the finger or through the proximal phalanx For this latter purpose, the Granberry bow offers a felicitous modification of the Kirschner wire method of fixation The Granberry bow is avail-

FIG 295 Intramedullary fixation of metacarpal shaft fracture An intra medullary pin has been introduced from the proximal fragment across the fracture down to the end of the distal fragment without entering the meta carpophalangeal joint (Courtesy of Dr J William Littler)

FIG 296 Transverse fracture of the metacarpal shaft Kirschner wires transfixing both fragments of the index metacarpal have been stabilized against the shaft of the metacarpal to the middle finger and have been incorporated in a plaster cast

been recommended for transmission of the traction in preference to elastic bands The advantage of the silk is that it affords more positive traction that can be increased by twisting the traction strands over a small Spanish windlass The direction of the traction force can be suitably altered by bending the plane of the banjo into any desired position in relation to that of the plaster cast in which it is fixed Traction is maintained until there is evidence of bony union Healing however, is not invariable and delayed union (Fig 298) or nonunion may occur (Fig 299) In the latter event, open operation and the insertion of a small bone graft may be necessary

Fractures of the Distal Portions of the Metacarpals

Fractures through the heads or necks of the metacarpal bones are disabling injuries that are difficult to treat because of inability to control the small distal fragment If the fragment is completely free, it may be possible to realign the two fragments by a simple dorsal splint (Fig 300) Usually, however, the small, distal

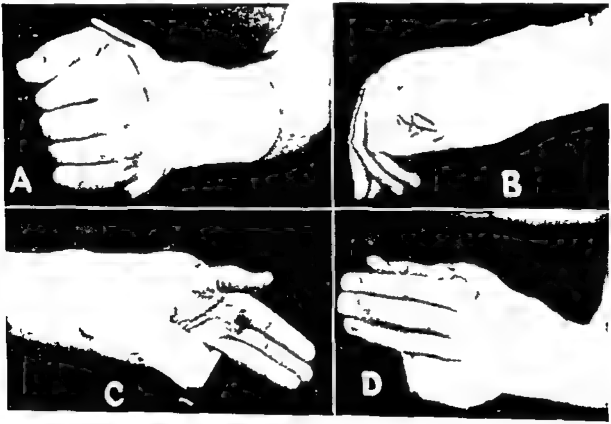


Fig 301 Fracture of the metacarpal head The Jahss method of treatment A pad is placed over the distal end of the proximal fragment (*A*) The proximal and middle phalanges of the finger are flexed to ninety degrees and upward pressure is made against the head of the proximal phalanx which is protected by a felt pad (*B*) The position is maintained by a plaster of Paris splint (*C*) which is held in place by a circular plaster of Paris bandage (*D*) (Reproduced from Jahss S Fractures of the metacarpals *J Bone & Joint Surg* *20* 178 1938)

FIG 299 Oblique fracture of metacarpals Nonunion at the base of the metacarpals to the index and middle fingers with malalignment of the fragments occurred despite prolonged cast immobilization Open operation with the insertion of intramedullary bone grafts was subsequently performed

FIG 300 Fracture of the neck of the fifth metacarpal The fragments were bowed dorsally and the head of the metacarpal was displaced into the palm of the hand Treated on a dorsal splint after manipulative reduction

able in several sizes for attachment to small wire needles which may be inserted into the base of the phalanx after drilling a small hole into the bone under local anesthesia Traction is obtained over a heavy wire banjo incorporated into a plaster of Paris cast that includes the lower part of the forearm the wrist and down to but not including the metacarpophalangeal joint (Fig 297) Heavy braided silk has

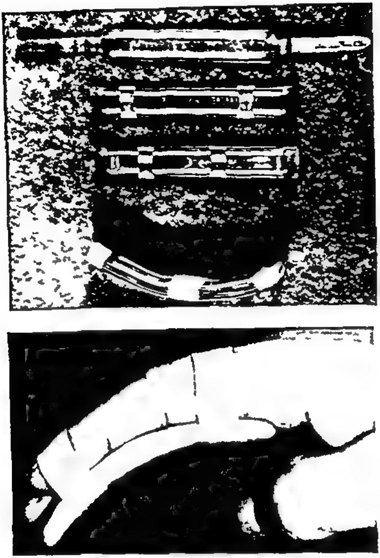


FIG 304 Volar splint for fractures of the fingers A volar splint may be fashioned from a piece of any malleable metal A convenient splint may be devised by binding together two or three ordinary paper clasps

realigned with the shaft without effort The position is thereafter maintained by upward pressure on the proximal phalanx which is flexed to a right angle on the metacarpal bone The second phalanx is similarly flexed to a right angle and is padded with felt to avoid pressure necrosis A piece of felt is placed over the dorsum of the shaft of the affected metacarpal so that downward counterpressure may be made against upward pressure along the proximal phalanx A plaster of Paris splint is applied over the dorsal aspect of the metacarpal and finger and is held in place by a circular plaster of Paris bandage, fixing the splint to the hand and the wrist

While this method serves to relax the distorting muscles and maintain position of the fragment, it frequently results in adhesions and contractures of the collateral ligaments with resulting restriction of finger joint motion To obviate this it has

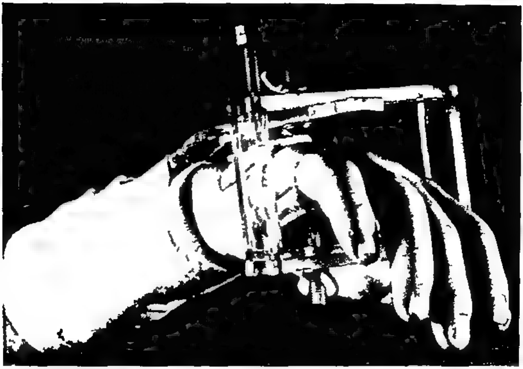


FIG 302 Goldberg splint for metacarpal fractures The splint is incorporated in a short forearm cast Downward screw pressure is made over *the felt pad protected distal portion of the metacarpal shaft Upward pres*sure is made through a felt pad protected screw over the head of the metacarpal and the base of the first phalanx (Courtesy of Armed Forces Institute of Pathology)

FIG 303 Flexion deformity of finger following Jahss method of treatment The alignment of the metacarpal is satisfactory but there is complete loss of extension at the proximal interphalangeal joint

fragment is impacted and cannot be easily realigned with the larger proximal fragment This leads to an unaesthetic depression of the knuckle and, in extreme cases, to inability normally to make a fist Fractures of this type may be corrected by the Jahss method (Figs 301 and 302)

The fracture site is completely mobilized so that the displaced fragment can be

FIG 306 Fracture of the second phalanx The characteristic volar angulation has been corrected and the fragments have been fixed by the introduction of an intramedullary pin (Courtesy of Dr J W Littler)

FIG 307 Fracture of the base of the second phalanx The volar portion of the base has been depressed and treatment must be in extension to exert traction through the volar portion of the joint capsule

been recommended that immobilization be discontinued after sixteen to seventeen days and that, if necessary, forcible manipulation of the finger joints be undertaken to restore mobility This procedure is painful and may require anesthesia for release of the periarticular adhesions Thereafter, persistent exercises to maintain motion must be carried out Despite this, there is frequently a marked residual limitation of motion that largely vitiates the value of this method (Fig 303)

FRACTURES OF THE PHALANGES

Fractures of the phalanges differ from the metacarpal fractures in that the angulation is almost invariably volar in direction, rather than dorsal This results from

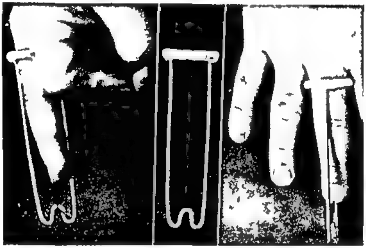


Fig 305 Finger splint for traction on phalangeal fractures The splint resembles the type devised by Thomas for use in fractures of the femur The ring makes counterpressure in the web of the fingers while the traction strip is fixed over the distal end of the splint (Reproduced from Milch H, The Thomas finger splint *Med J Rec* 1928)

the unbalanced action of the lumbrical and extensor muscles and applies particularly, therefore to fractures of the proximal and distal portions of the middle phalanges Where there is definite volar angulation with dorsal displacement of the distal fragment, treatment must be in flexion on a curved volar splint Such splints can be cut from strips of aluminum or other similar metal, and can be readily fashioned from ordinary paper fasteners bound together by adhesive tape and curved to fit the finger (Fig 304)

Where there is no displacement of the fragments and simple immobilization is all that is necessary gentle traction may be exerted through a finger splint similar to that devised by Thomas for traction in the lower extremity (Fig 305) Where the volar angulation cannot be corrected by traction or splinting intramedullary fixation must be employed (Fig 306)

FIG 306 Fracture of the second phalanx The characteristic volar angulation has been corrected and the fragments have been fixed by the introduction of an intramedullary pin (Courtesy of Dr J W Littler)

FIG 307 Fracture of the base of the second phalanx The volar portion of the base has been depressed and treatment must be in extension to exert traction through the volar portion of the joint capsule

Fractures of the proximal portion of the middle phalanx (Figs 307 and 308) as well as avulsion fractures of the base of the distal phalanx must be treated in extension Immobilization of the distal phalanx in extension for the treatment of mallet-finger should be carried out with the proximal phalanx fully flexed This

Fig 308 *Fracture of the base of the second phalanx* A small portion of the base has been avulsed from the dorsal aspect To secure realignment the distal portion of the shaft of the second phalanx must be placed in complete extension

tends to relax the flexor tendons and so minimizes the tendency toward displacement of the larger distal portion of the phalanx away from the small chip fracture

Crushing fractures of the terminal tuft of the distal phalanx usually require little attention other than protection from inadvertent blows against the tip of the finger Where the fragments are displaced gentle molding will often serve to restore the contour of the finger In fractures of the distal phalanx, only the involved finger should be immobilized Failure to maintain mobility of the other finger invariably results in prolonged disability resulting from stiffness

SECTION IV

The Appendicular Skeleton Lower Extremity

CHAPTER 18

Fractures of the Pelvic Girdle

Fractures of the pelvis are not rare They appear as isolated fractures of the individual bones or as more complicated fractures involving several of the bones and the pelvic ring Simple fractures may arise after a fall or a direct blow or as the result of muscular avulsions The more complicated fractures usually result from severe crushing injuries As in fractures of other parts of the axial skeleton, the outlook for life and functional recovery in these latter fractures is determined more by the associated injuries than by the fracture itself These may include injuries to the kidney liver, or spleen and, in the pelvis particularly, the ureter, bladder, urethra, or rectum Even apparently minor fractures of the pelvis may be associated with such visceral injuries

Every patient with a suspected fracture of the pelvis should be catheterized If there is gross or microscopic hematuria, the source of this bleeding must be determined by cystography, intravenous pyelography, and, if necessary, by cystoscopy If the bladder cannot be catheterized, the possibility of damage to the urethra must be contemplated and the danger of urinary extravasation must be forestalled by suprapubic cystotomy Injury to the rectum should be sought for by gentle rectal palpation and, where indicated, by proctoscopy While treatment of these complications may be the obligation of the fracture surgeon, it is unquestionably wiser to have the collaboration of a urologic or abdominal surgeon in their management

Isolated Fractures of the Pelvis

Isolated fractures of the pelvic bones usually do not require more than rest in bed and expectant treatment They include fractures of the wing of the ilium, the iliac spines, the body and ramus of the ischium, the sacrum, the coccyx, the pubic ramus, and separations of the symphysis pubis

FRACTURES OF THE ILIUM

Fractures of the Ala

Fracture of the wing of the ilium results from crushing injuries and may involve varying amounts of the bone Displacement is usually slight and, in any event, insignificant The patient may be made comfortable for motion in bed simply by encircling the whole pelvis by an adhesive tape dressing This should be applied from at least the level of the greater trochanter to well above the iliac flare and should be first applied to the injured side by rolling the patient onto the sound side After the affected side has been immobilized by adhesive strapping extending from the symphysis pubis anteriorly to beyond the mid line posteriorly, the patient may be gently rolled onto the injured side and similar straps be applied to the un-

Fig 309 Avulsion fracture of the anterior superior iliac spine There is downward displacement of the fractured fragment

affected side This serves to encircle the entire pelvis and immobilizes the fractures The strapping should be left in place for two or three weeks, after which a light canvas pelvic support should be fitted to the patient The belt should be worn until all symptoms have disappeared Bed rest is necessary only for as long as the patient complains of pain Painless walking can be undertaken even though bony union may not be complete

AVULSION FRACTURES OF THE ILIAC SPINES

Avulsion of the anterior superior iliac spine usually results from a forceful contraction of the sartorius muscle (Fig 309) avulsion of the anterior inferior iliac spine from a forceful contraction of the rectus femoris muscle (Fig 310) Both usually occur during strenuous activity such as running or football playing In each case, the fragment is displaced downward, but usually only to a slight distance Pain on motion is the presenting symptom and affords the primary indication for

FIG 310 Avulsion fracture of the anterior inferior iliac spine There is slight separation of the spine at the attachment of the rectus femoris muscle

treatment The patient should be merely put at rest in bed It has been stated that the thigh should be put in flexion to relax the tension on the avulsing muscles This is an unnecessary maneuver and does not at all assist in replacing the fragment Healing usually takes place with the fragment unreduced and the awkward position in bed merely serves to annoy the patient and to complicate nursing care The patient may be permitted to resume his normal activities as soon as the pain has subsided

FRACTURES OF THE ISCHIUM

Fractures of the Body and Tuberosity

Fracture of the body of the ischium in the adult is a very rare injury and results from direct violence such as a fall in the seated position blows directly against the tuberosity, or from penetrating objects (Fig 311) Displacement of the frag-

Fig 311 Fracture of the body of the ischium The ischium has been fractured through both rami with a slight downward displacement of the anterior end

ments is usually minimal No treatment other than complete bed rest is necessary when the fracture is simple When the fracture is compound, it is the treatment of the local wound that engages attention

Apophyseal separation of the ischial tuberosity is a characteristic injury in adolescents It results from apophyseal avulsion by the action of the hamstring muscles and is never seen after the age of twenty-five years at which time closure of the apophysis occurs The small fragment to which the hamstring muscles are attached is displaced downward and appears characteristically as a hemispherical or crescentic shadow below and posterior to the ischial tuberosity (Fig 312) Symptoms are invariably exacerbated by strenuous activity and mitigated by restriction of activity No treatment other than avoidance of excessive activity is indicated in most cases The patient may be permitted to be ambulant unless the pain is unbearable, in which instance simple bed rest until the pain has subsided is all that is necessary Healing usually occurs if the displacement is not excessive (Fig 313)

FIG 312 Ischial apophysiolysis acute stage A faint crescentric shadow below the body of the ischium on the right side is the result of avulsion by the hamstring muscles (Reproduced from Milch H, Ischial apophysiolysis A new syndrome *Clinical Orthopedics 2* 184, 1953)

FIG 313 Ischial apophysiolysis healing stage The distance between the avulsed ischial apophysis and the body of the ischium is gradually filled in by irregular masses of callus When healing is complete the only indication of the antecedent lesion will be a slight thickening and irregularity of the tuberosity of the affected ischium (Reproduced from Milch H Ischial apophysiolysis A new syndrome *Clinical Orthopedics 2* 184 1953)

No attempt should be made at operative replacement of the fragment If there is wide separation and the avulsed fragment impedes normal sitting, however, the fragment should be removed and the hamstring muscles reattached wherever possible If excision is necessary, the avulsed ischial apophysis can be easily approached by a longitudinal incision along the posterior aspect of the thigh, between the great trochanter and the ischial tuberosity The incision need not extend above the level of the lowermost fibers of the gluteus maximus and the only structure to be avoided is the sciatic nerve which is retracted laterally

Fractures of the Ramus of the Ischium

Isolated fracture of the ischial ramus is usually due to a direct blow or a fall astride Displacement is commonly minimal, owing to the splinting action of the unaffected pubic ramus There may, however, be extensive hemorrhage into the perineum and even intrapelvic bleeding, which may lead to transitory genitourinary difficulties Treatment is by simple rest in bed until pain has subsided and there is evidence of fracture healing Sufficient healing usually occurs within three to four weeks and the patient may then gradually resume normal activity

Stress fractures occasionally occur at the ischiopubic junction They are characterized clinically by pain and roentgenographically by an area of osteolysis at the ischiopubic junction They must be differentiated from tumors or inflammations in this region (Fig 314) Healing usually occurs with bed rest Under normal activity, symptoms may be prolonged for a year or more before healing occurs (Fig 315)

Fig 314 Stress fracture at the ischiopubic junction There is an area of radiolucency with a periosteal reaction at the junction of the descending ramus of the pubis and the ramus of the ischium (Courtesy of Dr A Friedman)

FIG 315 Healed stress fracture of the ischiopubic junction The radiolucent area has been reconstituted by new bone formation This roentgenogram was taken one year after that shown in Figure 314 (Courtesy of Dr A Friedman)

FIG 316 Fracture of the ischial spine and sacrum There is an irregularity at the base of the ischial spine A fragment of the left lateral wall of the sacrum has been displaced outward (Reproduced from Burman M S and Sinberg S E Tear of the sacrospinous ligament *Bull Hosp Joint Dis* 8 69 1947)

Fractures of the Ischial Spine

Isolated fracture of the ischial spine is exceedingly rare (Figs 316 and 317) No treatment is required and satisfactory healing may be expected Displacement is of no consequence in males, but in women protrusion of the ischial spine into the pelvic cavity may so shorten the interspinous diameter as to be a cause for dystocia and may necessitate Caesarian section at the termination of pregnancy

Fig 317 Old healed fracture of the ischial spine The ischial spine projects into the pelvic cavity and because of decrease of the interspinous diameter may act as a cause of dystocia (Reproduced from Burman M S Tear of the sacrospinous and sacrotuberous ligaments *J Bone & Joint Surg 34A* 331 1952)

FRACTURES OF THE SACRUM

Isolated fractures of the sacrum are usually transverse, but may be longitudinal in direction involve the lower portion of the bone and occur as the result of direct blows (Fig 316) Displacement is usually minimal and requires nothing more than rest in bed or at most, firm strapping of the buttocks Occasionally a marked forward displacement may be seen with injury to the lower sacral nerves and resultant disturbance of function of the external anal sphincter of sensation in the perineal region and of sphincter control of the bladder and urethra Where there has been marked forward displacement, gentle manual reposition per rectum or per vaginam has been suggested This should be undertaken with the greatest

timidity, since laceration of the wall of either of these structures may convert a closed into a seriously contaminated compound fracture involving the retroperitoneal space

FRACTURES OF THE COCCYX

Fractures of the coccyx arise as a consequence of direct trauma, either falls landing astride a resistance, such as a railing or wooden horse, or during obstetrical maneuvers Displacement is minimal but forward angulation may result from the pull of the anococcygeus muscle

The x ray is frequently of little value in diagnosis, which is most readily established by eliciting pain by motion of the coccyx on rectal examination

Pain on sitting walking stairs, or defecation is severe and should be treated by sedation, sitz baths, and strapping of the buttocks During the first week or so after fracture, the patient will be happiest in bed but, thereafter, may be permitted up and about Sitting whether on a hard or a soft seat, may be painful, but the pain may be relieved by the use of an inflated rubber ring Occasionally pain is persistent and if, after several months, it has not been relieved, coccygectomy is justifiable

The operation is carried out with the patient in the prone position with the legs dependent and the pelvis elevated A horseshoe-shaped incision is made, with the apex at the level of the sacrococcygeal joint and its arms on either side of the intergluteal crease After reflection of the skin flap, the posterior aspect of the sacrum and coccyx is disclosed The coccyx may be removed either from above downward or in a retrograde manner by fixing a towel clip to its terminal end The tip of the coccyx and its anterior aspect are then sharply freed, care being taken to avoid injury to the underlying rectum and the adjacent lateral sacral arteries The dead space remaining must be obliterated and the wound may then be closed without drainage The results of coccygectomy in traumatic cases are satisfactory with immediate relief of pain

FRACTURES OF THE PUBIS

Fractures of the Pubic Ramus

Fracture of the ramus of the pubis is most commonly the result of direct violence and is normally not associated with any visceral injury Displacement is minimal and requires no treatment other than rest in bed for a period of three or four weeks at which time weight bearing may be resumed if painless (Fig 318)

Separation of the Symphysis Pubis

Separation of the symphysis pubis is a not uncommon injury after difficult obstetrical deliveries It occurs less frequently in males as a result of direct trauma to the pubis (Fig 319) The patients complain of severe pain and difficulty in walking Pain usually subsides during the normal period of postpartum involution

FIG 318 Fracture of the pubic ramus There is a longitudinal fracture of the descending ramus of the pubis with practically no separation of the fragments The fracture line passes medial to the ischiopubic junction

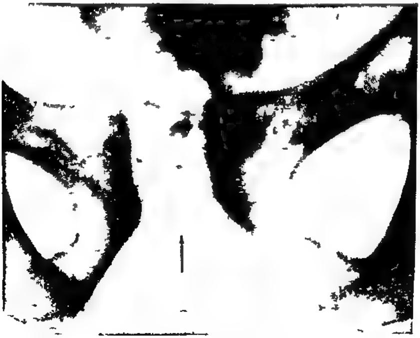


FIG 319 Traumatic separation of the symphysis pubis There is a widening of the space between the bodies of the pubis as a consequence of a direct anteroposterior compressing force

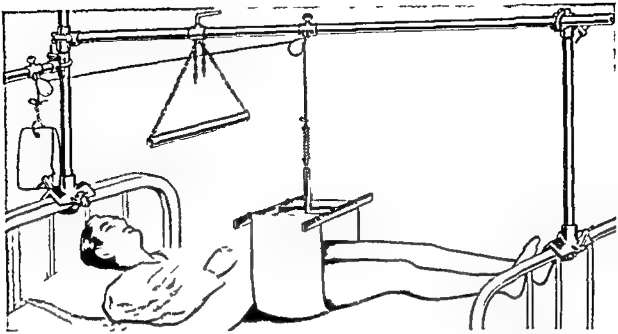


FIG 320 Pelvic sling for pelvic fractures Compression against the side of the pelvis may be increased by crossing the arms of the sling (Courtesy of Gilbert Hyde Chick Co)

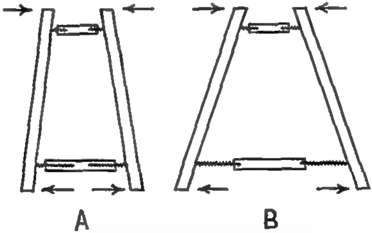


FIG 321 Jahss method for pelvic compression *A* illustrates the position of the legs in plaster of Paris cylinders at the time of application of the turnbuckle casts By shortening the proximal turnbuckle and extending the lower turnbuckle *B* lateral compressing forces are exerted against the sides of the pelvis through the femora (After Jahss S A Injuries involving the pelvis *Am J Surg* *43* 394 1939)

In instances where the symptoms persist and the separation is not overcome, strapping of the pelvis or suspension in an overhead sling for a period of six to eight weeks usually results in a subsidence of the symptoms (Fig 320)

Where the separation cannot be overcome by this method, direct compression may be exerted by the Jahss method (Fig 321) This employs the principle of

FIG 318 Fracture of the pubic ramus There is a longitudinal fracture of the descending ramus of the pubis with practically no separation of the fragments The fracture line passes medial to the ischiopubic junction

FIG 319 Traumatic separation of the symphysis pubis There is a widening of the space between the bodies of the pubis as a consequence of a direct anteroposterior compressing force

in hazardous occupations Largely as the result of high speed locomotion, fractures of the pelvic ring have become more common than formerly in the female This imposes a different therapeutic objective In the male, the essentials of therapy are encompassed by the restoration of the pelvis so as to permit weight bearing and the resumption of work In the female, there must be added the objective of restoration of the normal internal diameters of the pelvis Failure to accomplish this may expose the woman of childbearing age to the necessity of Caesarian section This alternative is, however, not so terrifying as to justify anything more than conscientious efforts to secure accurate alignment by closed methods Overenthusiastic attempts at manual replacement or overzealous surgical interference may well expose the patient to consequences far more serious than can be envisioned from failure to restore the anatomical configuration

Fractures of the pelvic ring usually involve two or more of the pelvic bones and may be divided into those that (1) affect the anterior portion of the pelvic ring either unilaterally or bilaterally, (2) affect the anterior ring on one side and the posterior ring on the opposite side, (3) affect the anterior and posterior portions of the pelvic ring on the same side, and (4) affect primarily the acetabulum

Fractures of the Anterior Ring

Fractures of the anterior ring are the result of crushing injuries either in the anteroposterior or lateral directions The fracture line may involve the ischial and pubic rami on one side or bilaterally and may occur at any point in their course (Fig 323) Depending upon the direction of the force, the fragments may be displaced backward or against one another leading to overriding Usually, the displacement is slight, but the danger of injury to the bladder and urethra is very

Fig 323 Unilateral fracture of anterior ring There is a vertical fracture of the ascending ramus of the pubis and the ischium with slight overriding of the fragments Complete healing from simple bed rest and suspension in a pelvic sling

turnbuckle constriction exerted through long leg casts A large turnbuckle is inserted in the plaster cast above the malleoli with a shorter turnbuckle four to five inches below the upper edge of the cast By shortening the upper turnbuckle and lengthening the lower turnbuckle force can be exerted on the pelvis through the inward action of the femoral heads, thus tending to approximate the margins of the separated symphysis pubis (Fig 322) Good functional results may be ex

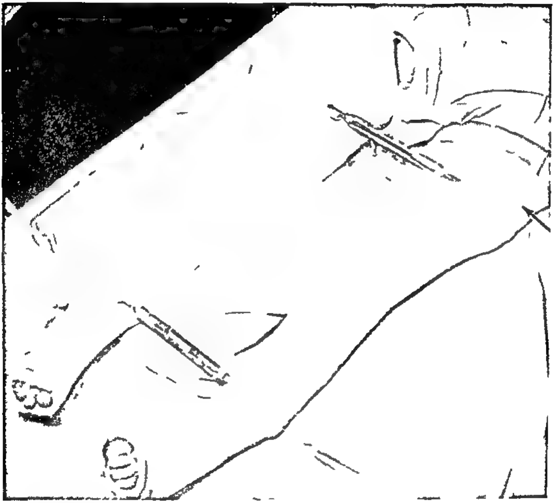


FIG 322 Jahss turnbuckle cast Method of applying the turnbuckle to the long leg plaster of Paris casts

pected even when complete restoration of normal alignment has not been attained Operative fusion of the symphysis is to be carefully avoided since it leads to marked disability presumably owing to excessive strains at the sacroiliac joints

FRACTURES OF THE PELVIC RING

Fractures of the pelvic ring result from severe crushing injuries and are the fractures most likely to lead to complicating injuries of the pelvic viscera Formerly, this type of fracture of the pelvic ring was encountered mainly in males engaged

in hazardous occupations. Largely as the result of *high speed locomotion, fractures of the pelvic ring* have become more common than formerly in the female. This imposes a different therapeutic objective. In the male, the essentials of therapy are encompassed by the restoration of the pelvis so as to permit weight bearing and the resumption of work. In the female, there must be added the objective of restoration of the normal internal diameters of the pelvis. Failure to accomplish this may expose the woman of childbearing age to the necessity of *Caesarean section. This* alternative is, however, not so *terrifying* as to *justify anything* more than conscientious efforts to secure accurate alignment by closed methods. Overenthusiastic attempts at manual replacement or overzealous surgical interference may well expose the patient to consequences far more serious than can be envisioned from failure to restore the anatomical configuration.

Fractures of the pelvic ring usually involve two or more of the pelvic bones and may be divided into those that *(1) affect the anterior portion of the pelvic ring* either unilaterally or bilaterally, (2) affect the anterior ring on one side and the posterior ring on the opposite side, (3) affect the anterior and posterior portions of the pelvic ring on the same side, and (4) affect primarily the acetabulum.

FRACTURES OF THE ANTERIOR RING

Fractures of the anterior ring are the result of crushing injuries either in the anteroposterior or lateral directions. The fracture line may involve the ischial and pubic rami on one side or bilaterally and may occur at any point in their course (Fig. 323). Depending upon the direction of the force, the fragments may be displaced backward or against one another, leading to overriding. Usually, the displacement is slight, but *the danger of injury to the bladder and urethra is very*

FIG. 323. Unilateral fracture of anterior ring. There is a vertical fracture of the ascending ramus of the pubis and the ischium with slight *overriding of the fragments*. Complete healing from simple bed rest and suspension in a pelvic sling.

great (Fig 324) Manual replacement is usually unnecessary and, in simple fractures, the patient can be treated by rest in bed Immobilization of the pelvis may be obtained by an encircling adhesive strapping Nursing care and the comfort of the patient are greatly facilitated by suspending the patient in an overhead sling Healing most commonly occurs in about six weeks, after which time a firm canvas belt extending from the upper edge of the pelvis down to and including the region of the

FIG 324 Bilateral fracture of the anterior pelvic ring Fracture of the ischial and pubic rami on the right side and fracture at the ischiopubic junction of the left side An indwelling catheter is in place and a cystogram has been performed (Courtesy of Dr H L McLaughlin)

great trochanter should be prescribed At this time, the patient may be permitted to begin weight bearing and ambulation

FRACTURES OF THE ANTERIOR AND POSTERIOR RINGS ON OPPOSITE SIDES

These fractures usually result from obliquely directed anteroposterior compressive forces and lead to an oblique distortion of the pelvis Where there has been no great displacement rest in bed or in a pelvic sling usually results in satisfactory healing Where there has been upward or downward displacement of one hemipelvis so that a disparity in limb length is inevitable efforts should be made to correct the deformity by use of the well leg countertraction method (Anderson) or by applying traction weights to the shorter limb As in other fractures of the pelvis, healing usually occurs within six to eight weeks and gradual ambulation may be permitted with the aid of crutches and the support of a canvas encircling belt after this time

FRACTURES OF THE ANTERIOR AND POSTERIOR RINGS ON THE SAME SIDE

These fractures are of the type described by Malgaigne as double vertical fractures and are shearing fractures due to anteroposterior compression. They are frequently complicated by upward displacement of the hemipelvis on the side of the injury. As a consequence, a shortening of the limb on the affected side is characteristic and every effort should be made to restore the relative length of the

FIG 325 Ischioacetabular (Walther's) fracture The fracture line passes through the ramus of the pubis and terminates in the region of the sacroiliac joint The entire medial wall of the acetabulum has been displaced inward without, however any protrusion of the femoral head into the acetabulum When healed this fracture presents the appearance of a unilateral Otto pelvis (Reproduced from Milch H Ischio acetabular fracture *Bull Hosp Joint Dis 16* 7 1955)

affected limb This has been accomplished by the Watson-Jones method of manual reduction

With the patient lying on the sound side, the affected limb is abducted in the plane of the normal limb and is held in this position by an assistant while downward pressure is made over the crest of the ilium on the involved side The resulting reduction should be verified roentgenographically and, if satisfactory, a short double hip spica extending from the chest wall down to above the knees should be applied and left in place for a period of about three months

If alignment is unsatisfactory reduction of the fracture and re-establishment of relative equality of limb length may be undertaken by the application of traction to

the shorter leg, while the patient is suspended in the pelvic sling Where reduction by means of skin traction is unsuccessful, considerably more force may be applied by the use of the well leg countertraction method If satisfactory realignment is attained, this traction should be continued for a period of two to three months and weight bearing should be interdicted until there is evidence of satisfactory bony

FIG 326 Ischioacetabular fracture There is central protrusion of the femoral head through the fractured floor of the acetabulum and evidence of arthritic manifestations in the femoral head (Courtesy of Dr D Raskind)

union Ambulation may be carefully resumed at this time with the aid of crutches and a canvas support to the pelvis

A variant of the vertical fracture is the so-called *ischioacetabular fracture* where the line of fracture passes through the ischial and pubic rami anteriorly, through the acetabulum and terminates posteriorly in the region of the sacroiliac joint (Fig 325) This fracture may result from a fall from a height or from lateral compression against the trochanter It results in a narrowing of the interspinous diameter of the pelvis and not infrequently in a traumatic arthritis of the hip joint (Fig 326)

Reduction is most difficult Manual reduction per rectum or per vaginam has

been recommended, but is strongly advised against Lateral traction with skeletal fixation in the trochanter has been reported successfully Probably the best method of securing closed reduction is that advocated by Jahss Two long leg casts are applied extending from the groin to below the malleoli Turnbuckles are incorporated in the cast above the malleoli and about four inches below the upper end of the leg casts By shortening the lower turnbuckle and lengthening the upper turnbuckle in an exactly contrary manner to that used for overcoming separation of the symphysis pubis, force is exerted on the upper end of the femora, which in

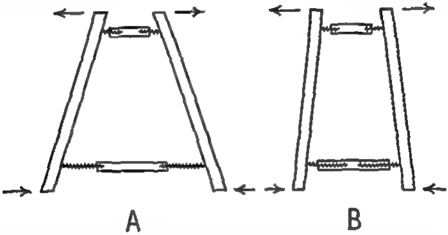


FIG 327 Jahss method for lateral pelvic traction (*A*) Position of the turnbuckles in the plaster casts before attempt at reduction (*B*) By lengthening the upper turnbuckle and shortening the lower turnbuckle the upper ends of the femora are pulled outward and exert lateral traction on the pelvic walls (After Jahss S A Injuries involving the pelvis *Am J Surg 43* 494, 1939)

turn exerts a lateral traction on the pelvic walls and thus tends to reduce the fracture (Fig 327)

The reduction should be accomplished as quickly as possible and the turnbuckle pressure should be increased daily until the x-ray shows satisfactory alignment The apparatus should then be maintained in place until there is roentgenographic evidence of satisfactory bony union about two to three months Gradual ambulation may then be permitted with the aid of crutches and the support of a canvas belt

Whether as a result of traction on the sciatic nerve at the time of fracture or as a result of direct contusion to the nerve, paralysis, particularly in the distribution of the peroneal nerve, is a common complication of this type of fracture At exploratory operation, no loss of continuity in the sciatic nerve may be demonstrated The patients manifest the signs of motor and sensory paralysis of the peroneal nerve and are frequently left with a residual foot drop that must be corrected by appropriate operative intervention The complication that may arise from a traumatic arthritis of the hip must be treated as arthritis of the hip from other causes

FIG 328 Superior rim fracture of the acetabulum Fracture of the superior rim is seen with upward displacement of the femoral head

FIG 329 Posterior rim fracture of the acetabulum The fractured rim fragment has been reduced and held in place by two screws (Courtesy of Dr O Kestler)

Fractures of the Acetabulum

Fractures of the acetabulum may be either rim fractures or central fractures *Rim fractures* are most common as the result of automobile accidents in which the head of the flexed femur is driven against the posterior margin of the acetabulum They have consequently been called dashboard fractures and result from blows against the knees in sudden decelerations of an automobile Fractures of the

Fig 330 Rim fracture of the acetabulum Old unreduced fracture of the acetabular margin with upward dislocation of the femoral head treated by Schanz type of subtrochanteric abduction osteotomy

superior rim of the acetabulum may result from falls landing on the feet (Fig 328) In both instances, there is usually a corresponding dislocation of the femur that remains unstable unless the fractured rim is replaced This must be done by open operation

Before the fractured fragments of the rim are replaced, a reduction of the dislocated femoral head is of the utmost importance Experience has demonstrated that avascular necrosis of the femoral head varies directly with the length of time before its replacement in the acetabular cavity This is so important that reduction under anesthesia has been advocated even in the presence of severe visceral in-

juries The actual fixation of the rim fracture can be deferred until such time as the patient's general condition warrants more extensive operation

For posterior rim fractures, the approach must be made through the posterior iliofemoral incision, extending from the posterior iliac spine down to the great trochanter For superior rim fractures, the approach may be made through the

FIG 331 Central fracture of the acetabulum The acetabular floor has been cracked in several places but without inward displacement of the floor of the acetabulum or of the femoral head

lateral iliofemoral incision extending from the anterior superior iliac spine to the base of the trochanter The fragment must be carefully reduced and this is possible only by traction on the limb during the course of the operation When accurate reduction has been obtained the fragment must be fixed in place by one or two screws into the pelvis (Fig 329)

The results of this procedure however elegant they may appear roentgenographically, are always doubtful because of the almost invariable development of

traumatic arthritis Where the marginal fragment has not been replaced or has not held in place, a persistent dislocation of the femur will ensue The resultant instability can be overcome by the performance of a Schanz type of subtrochanteric osteotomy (Fig 330)

Central fractures of the acetabulum may result from falls or from lateral compressions of the femora and have even been described as a result of falls on the sacrum or shoulder They are characterized by fracture of the acetabular floor with or without inward protrusion of the medial wall of the acetabulum Where the acetabular floor has been merely fractured without medial displacement, traction should be applied to the limb until there is evidence of firm healing (Fig 331) This may require several months Premature weight bearing will result in a gradual inward

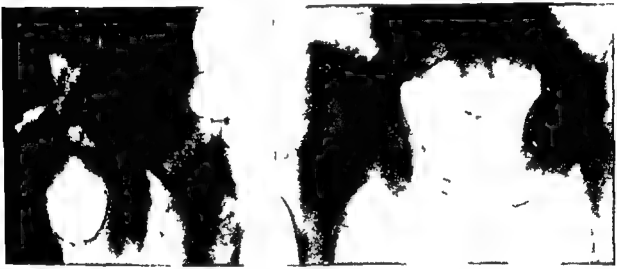


FIG 332 Otto s pelvis (protrusio acetabuli) Following healing of a central fracture of the acetabulum (*left*) there is inward protrusion of the medial pelvic wall (*right*)

displacement of the medial wall characteristic of the so-called Otto s pelvis (protrusio acetabuli) (Fig 332) Where the floor is merely pushed inward, lateral traction through the great trochanter or spreading the thighs by the Jahss method of lateral pelvic traction may be of value in preserving motion of the hip joint

Where the femoral head has actually penetrated the floor of the acetabulum and projects into the pelvic cavity, the fragments of the acetabular floor grip the femoral neck so firmly that any effort short of extensive operative intervention is fruitless In such cases the x-ray presents the appearance of a very marked Otto type of pelvis Motion is limited and usually painful In these cases as in all cases involving the acetabulum, the incidence of traumatic arthritis of the hip joint is extremely high and the prognosis as regards the return of function must be especially guarded As in other forms of arthritis where the acetabulum is involved the question of therapy is still under ardent discussion Prostheses of the femoral head are clearly not to be considered since the site of the pathology is evidently the acetabulum and not the femoral head Fusion of the hip may be considered in unilateral cases, but the resection angulation operation is recommended In bilateral cases the resection angulation operation is the procedure of choice (See *infra*)

CHAPTER 19

Fractures of the Femur

Like other long bones, fractures of the femur may occur in the shaft or at either extremity Fractures in this bone, however, present particular problems because of the anatomical configuration of the bone, its weight bearing function, and the severe metabolic response, similar to that of major, third degree burns, that they may excite The treatment of such fractures, therefore, involves not only attention to mechanical realignment of the fractured fragments, so as to preserve joint function both at the hip and the knee, but also care of patients who are often desperately ill The therapeutic problem is further compounded by the fact that the fractures frequently occur in elderly, debilitated individuals who are particularly prone to the development of pulmonary and cardiovascular complications

Experience has repeatedly demonstrated that, particularly in the elderly, fractures of the femur are acute, surgical emergencies and that the end results in patients treated early in the postresuscitative period are vastly superior to those obtained where treatment has been instituted later after misguided efforts to build up the patient In femoral shaft fractures, the effective circulating blood volume may be diminished by as much as two liters and there is virtually constant internal hemorrhage amounting to about one liter of blood Blood volume deficit must be immediately replaced the diagnosis established, and proper therapy promptly instituted Diagnosis is exclusively the function of the roentgenologist and, beyond observation of the existence of an obvious deformity, clinical examinations are largely useless

FRACTURES AT THE UPPER END

Although they are most frequently encountered in older individuals, fractures at the upper end of the femur may occur in all age groups In general, fractures in this region may be divided into four groups (1) subcapital fractures, (2) transcervical fractures, (3) intertrochanteric fractures, and (4) fractures of the trochanter Subcapital and transcervical fractures are intracapsular, while intertrochanteric and trochanteric fractures are extracapsular The subcapital fractures

may be either of the abduction or adduction types, but the transcervical and intertrochanteric fractures are almost constantly of the adduction type

The abduction types are characterized by inward angulation at the site of fracture, with outward displacement of the distal fragment and upward displacement of

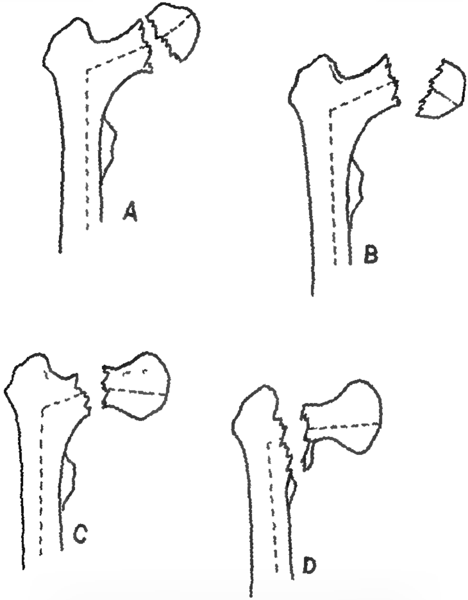


Fig 333 Fracture types at the upper end of the femur (*A*) Subcapital abduction fracture (*B*) Subcapital adduction fracture (*C*) Transcervical adduction fracture (*D*) Intertrochanteric adduction fracture

the proximal fragment, tending to result in an increase in the angle of the femoral neck (coxa valga) The adduction fractures, conversely, are characterized by an outward angulation at the fracture site with inward displacement of the distal fragment and downward displacement of the proximal fragment, tending to lead to a decrease in the angle of the femoral neck (coxa vara) (Fig 333)

Subcapital Fractures

In children, *subcapital fractures* appear primarily in the form of *epiphyseal separations* at the upper end of the femoral neck These occur mainly at the age of adolescence and have been variously designated as adolescent or epiphyseal coxa vara, upper femoral epiphysiolysis, and slipped capital femoral epiphysis It has been erroneously attributed to many causes and specifically to an underlying epiphyseal dysplasia owing to a postulated though undemonstrated endocrinopathy While the condition is more commonly seen in obese children of the Froelich type, it may also occur in tall, thin individuals (Fig 334) From the fact that all phases

Fig 334 Upper femoral epiphysiolysis (coxa anteverta) Bilateral congenital coxa vara occurring in a tall thin individual in whom there was also a separation of the capital epiphysis on the left side (Epiphysiolysis)

of the condition including the so-called preslipped phase, have been reproduced experimentally in monkeys and that the condition may be satisfactorily controlled by the prevention of external rotation of the distal portion of the femoral shaft it may be presumed that the condition is a simple external rotation fracture resulting from the torque effect produced by body weight that exceeds the intrinsic strength of the epiphyseal plate attachment

Although the condition has been generically designated as epiphyseal coxa vara this applies only to the late phase of the condition In its earliest manifestations upper femoral epiphysiolysis presents the roentgenographic appearance of a broadening of the epiphyseal plate This has been called the preslipped phase (Fig 335) Actually there is no such entity Lateral roentgenograms demonstrate conclusively that the so-called broadening is an optical illusion due to a malalignment of the femoral head on the neck which visualized on the anteroposterior view of the femoral head presents an oblique view of the upper end of the femoral neck (Fig 336) This phase of the slowly progressive epiphyseal fracture has been designated

Fig 335 Upper femoral epiphysiolysis so-called preslipped phase There is only slight broadening of the epiphyseal line but the existence of actual slipping is indicated by the loss of the hump-like projection (*arrow*) of the femoral head that normally exists at the superior border of the collo-capital junction

Fig 336 Upper femoral epiphysiolysis so called preslipped phase On the lateral view of a case similar to Fig 335 there is definite evidence of malalignment of the axis of the capital epiphysis with the axis of the neck Actual slipping is clearly present

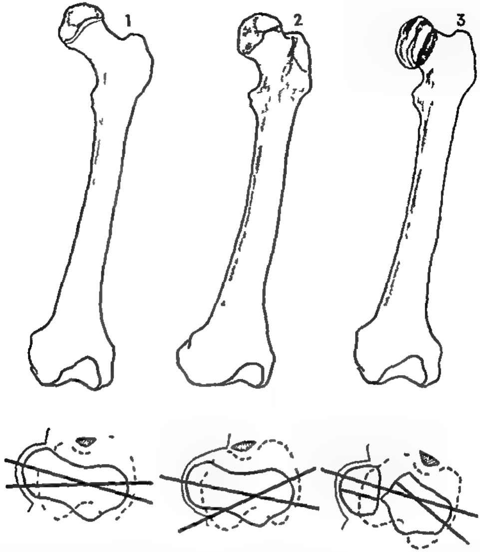


FIG 337 Coxa anteverta and anteversion of the femoral neck End-on views of the femur and the corresponding anteroposterior roentgenographic views in the hips of (*1*) normal individuals (*2*) patients with congenital dislocations of the hip and (*3*) patients with epiphysiolysis In (*1*) the femoral neck is of normal length and is anteverted fifteen to twenty five degrees forward from the bicondylar axis The hump is present at the collocapital junction there is no sub capital shadow and the lesser trochanter is of normal size In (*2*) the femoral neck is foreshortened the angle between the axes is increased the hump is present at the collocapital junction there is no subcapital shadow and the lesser trochanter is excessively prominent due to external rotation of the limb In (*3*) the neck is foreshortened the angle between the neck and the bicondylar axis is diminished the hump at the collocapital junction has disappeared a subcapital shadow is present at the upper end of the femoral neck and the lesser trochanter is excessively prominent owing to external rotation of the femoral shaft

FIG 338 Emergency treatment of epiphysiolysis (coxa anteverta) Early case of bilateral slipped capital femoral epiphyses The patient is in bed with both legs internally rotated in plaster boots that are held fixed by a connecting bar Abduction is of value only to facilitate nursing care In unilateral cases a single plaster of Paris boot with a flange to maintain internal rotation is sufficient

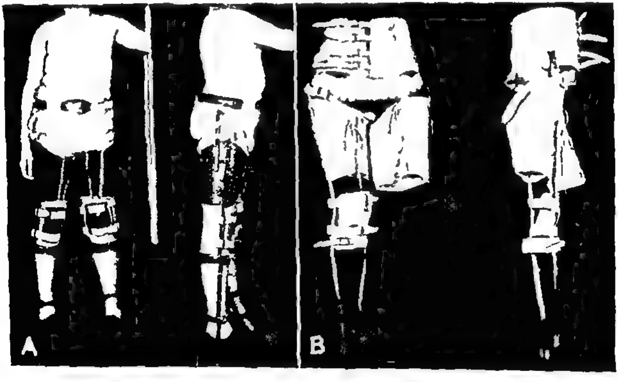


FIG 339 Brace treatment of epiphysiolysis (*A*) In bilateral cases two long leg braces with movable knee joints are connected by a pelvic band which serves to maintain internal rotation (*B*) In unilateral cases the brace on the normal side need only extend to above the knee and serves to *maintain internal* rotation of the affected limb through the pelvic band

as coxa anteverta or more properly, collum antevertum, since it is the femoral neck (collum) that rotates anteriorly (anteversion) while the head remains fixed in the acetabulum by the tendon of the iliopsoas muscle

The term *coxa anteverta (collum antevertum)*, which is characteristic of the early manifestations of upper femoral epiphysiolysis, must be carefully differentiated from the condition designated as *anteversion of the femoral neck* which is characteristically seen in congenital dislocations of the hip The former is characterized by an external rotation, and consequently an anterior displacement of the

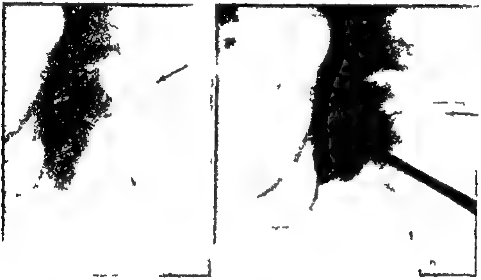


Fig 340 Unilateral epiphysiolysis (*Left*) The loss of the collo capital hump apparent broadening of the left epiphyseal line with foreshortening of the femoral neck and prominence of the lesser trochanter establish the diagnosis of an external rotation epiphyseal separation (*Right*) The capital epiphysis has been realigned with the axis of the neck The collocapital hump has been restored and the fragments are held by Telson wires that penetrate the neck and fix the capital epiphysis

femoral neck and shaft beneath the femoral head, while in congenital dislocation there is an internal rotation of the femoral shaft with respect to both the femoral head and neck

Coxa vara or more properly caput varum occurs only when the externally rotated neck fracture has reached the point where the neck no longer impinges against the undersurface of the capital epiphysis and the femoral shaft may then be actually displaced upward During all the so called phases of the condition it is the neck and shaft that rotate externally while the head retains its normal relationship to the acetabulum It is only when union of the fractured fragments has occurred in malposition and forward progression with the knee in the sagittal plane is undertaken that the femoral head is pushed posteriorly and out of the acetabulum by internal rotation of the limb

Since the mechanism of the production of upper femoral epiphysiolysis is external rotation of the neck beneath the capital epiphysis, rational treatment need only be directed to the prevention of external rotation of the leg Treatment must be undertaken early during the collum antevertum stage Seen in this stage, the epiphyseal fracture should be considered as an emergency and weight bearing must be immediately prohibited, since the slightest increase in external rotation may serve to convert a mildly malaligned fracture into a complete separation with coxa vara

Fig 341 Subcapital abduction fracture of the femoral neck The head is in valgus and apparently impacted The subcapital shadow seen through the shadow of the head is cast by the anteverted femoral neck

A flanged plaster of Paris boot extending from the toes to below the knee should be applied immediately to enforce internal rotation of the extremity (Fig 338) The bedside table should be placed on the side of the affected limb so that when the patient reaches to the table the body weight will tend further to prevent external rotation This is a very important detail, since partial slipping may be converted into complete separation by so slight a motion as is involved in turning the trunk to the opposite side The flanged boot should be left in place until definitive treatment either by means of an internal rotation brace (Figs 339 and 340) or by pin fixation of the fractured fragments has been effected

In unilateral cases, the internal rotation brace treatment is accomplished by means of a long leg brace applied to the affected limb and fixed in internal rotation against a short thigh brace on the unaffected limb, which is held in position by a pelvic band A lock knee joint should be incorporated in the long leg brace In bilateral cases, long leg braces should be applied to each of the extremities and

each should be turned into the maximum of internal rotation against the stabilizing band The braces must be worn constantly, day and night, until there is x-ray evidence of complete closure of the epiphyseal plate usually about one year The patients may be permitted to engage in all forms of activity provided that the braces are worn at all times

The brace treatment is a completely satisfactory method of treatment and should be employed in preference to open operative reduction It has the disadvantage of

FIG 342 Subcapital fracture of the femoral neck The abduction fracture in the patient shown in Fig 341 disimpacted while he was lying in bed with resulting conversion of the valgus into a varus position of the femoral head

enforced brace-wearing and the necessity for repeated mechanical repairs Where the use of the brace is objectionable pin fixation can be carried out very easily by means of Telson wires in preference to the Smith-Petersen nail (Fig 340) Two or three wires should be inserted through a small lateral incision over the base of the trochanter and should penetrate the capital fragment without perforating its cartilaginous surface No attempt should be made to realign the fractured fragments by force since it is almost impossible to control the small capital fragment The roentgenographic appearance of reduction after manipulation is unquestionably illusory and is to be attributed to the fact that the x ray films are obtained with the limb in internal rotation

No immobilization is necessary in either form of treatment Strenuous exercise

is, in general, inadvisable but may be undertaken even before bony union has occurred across the epiphysis Ambulation may be permitted immediately The wires may be left in place permanently or they may be removed after healing is complete Premature removal of the wires before complete bony union has occurred may lead to recurrence of the condition

In contradistinction to the treatment of coxa antevertа, if the patient is seen shortly after complete separation has occurred and there is a coxa vara deformity,

Fig 343 Subcapital abduction fracture of the femoral neck To assure maintenance of position two large Telson wires have been inserted to transfix the capital fragment

manipulative realignment of the fragments may be attempted This is possible, however only up to about two weeks after the acute episode Thereafter, manipulative realignment is probably impossible, owing to the early formation of callus, and attempts at replacement are usually ineffectual In this situation, open reduction for replacement of the head has been advised but the results have not been entirely satisfactory largely because of the impairment of the capsular circulation that such procedures involve It has been shown statistically that in cases in which union in malposition has occurred the end results vary inversely with the extent of the

FIG 344 Subcapital abduction fracture of the femoral neck The position has been maintained by the insertion of a Smith Petersen nail

surgical intervention The best results have been achieved by simple internal rotation osteotomy to restore axial alignment without any effort to achieve anatomical reposition

In the adult, *subcapital fractures* may be either of the abduction or adduction types

Abduction fractures are usually impacted along their outer aspect The fracture line is frequently horizontal and weight bearing merely serves further to impact the

FIG 345 Subcapital adduction fracture of the femoral neck The head is sclerotic with aseptic necrosis of the neck and there is marked upward displacement of the distal fragment

fractured surfaces Because of this it has been frequently maintained that *internal* fixation is not necessary or indicated in these cases This is not invariably the case, however, and even with the patient confined to bed an abducted impacted subcapital fracture may be displaced under the influence of *muscular pull* and converted into an adduction type of fracture (Figs 341 and 342) It is unquestionably more desirable to assure the maintenance of position by the insertion of *Telson* wires (Fig 343), a bone screw or, if the fragment is sufficiently large, of a Smith-Petersen triflanged nail (Fig 344)

No immobilization is necessary and the patient may be permitted to sit up in bed or a wheel chair almost immediately after operation Walking with crutches may be permitted as soon as the postoperative reaction has subsided, but it is probably safer to protect against full weight bearing by the use of a Thomas walking brace for a period of six to nine months

FIG 346 Prosthesis for nonunited subcapital fracture This patient was originally treated by Smith Petersen nailing The path of the previously inserted nail can still be seen Union did not occur and a prosthesis was inserted

Adduction types of subcapital fractures present an entirely different problem from the abduction types It is difficult to reduce such fractures and even if reduced difficult to maintain in position Aseptic necrosis is a common sequel (Fig 345) and, because of this open operation with prosthetic replacement of the fractured femoral head has come into favor

Many different types of prostheses have been devised Generally speaking the plastic devices are not as satisfactory as those made of metal For the insertion of any prosthetic femoral head approach to the hip joint may be made either through the anterior iliofemoral so called Smith-Petersen incision, through the lateral iliofemoral, so-called Watson-Jones incision, or through the posterior iliofemoral, so-

called Gibson incision The capsule is opened and the fractured fragment is removed The remaining stump of the neck of the femur is then resected close to the intertrochanteric line A reamer, to permit insertion of the prosthesis, is passed through the base of the neck into the shaft of the femur The prosthesis is inserted and the wound is closed without any effort at resuturing the capsule (Fig 346)

FIG 347 Dislocation of femoral prosthesis This patient was treated by a prosthesis after an unsuccessful pinning of the hip The prosthesis dislocated and the resection angulation operation was ultimately performed

The results of prosthetic replacement of the femoral head are far more satisfactory in the treatment of recent subcapital fractures of the femoral neck than they have been in the treatment of old malunited fractures or in arthritis of the hip joint in both of which situations there is involvement of the acetabular cavity as well as of femoral head Even following recent fractures, however, prosthetic replacement may be followed by persistence of pain limitation of motion, and dislocation of the prosthetic femoral head (Fig 347) In such instances, reoperation with the insertion of another prosthesis is frequently fruitless and it is preferable

No immobilization is necessary and the patient may be permitted to sit up in bed or a wheel chair almost immediately after operation Walking with crutches may be permitted as soon as the postoperative reaction has subsided, but it is probably safer to protect against full weight bearing by the use of a Thomas walking brace for a period of six to nine months

FIG 346 Prosthesis for nonunited subcapital fracture This patient was originally treated by Smith Petersen nailing The path of the previously inserted nail can still be seen Union did not occur and a prosthesis was inserted

Adduction types of subcapital fractures present an entirely different problem from the abduction types It is difficult to reduce such fractures and even if reduced, difficult to maintain in position Aseptic necrosis is a common sequel (Fig 345) and, because of this open operation with prosthetic replacement of the fractured femoral head has come into favor

Many different types of prostheses have been devised Generally speaking the plastic devices are not as satisfactory as those made of metal For the insertion of any prosthetic femoral head approach to the hip joint may be made either through the anterior iliofemoral so-called Smith-Petersen incision through the lateral ilio femoral so called Watson-Jones incision, or through the posterior iliofemoral, so-

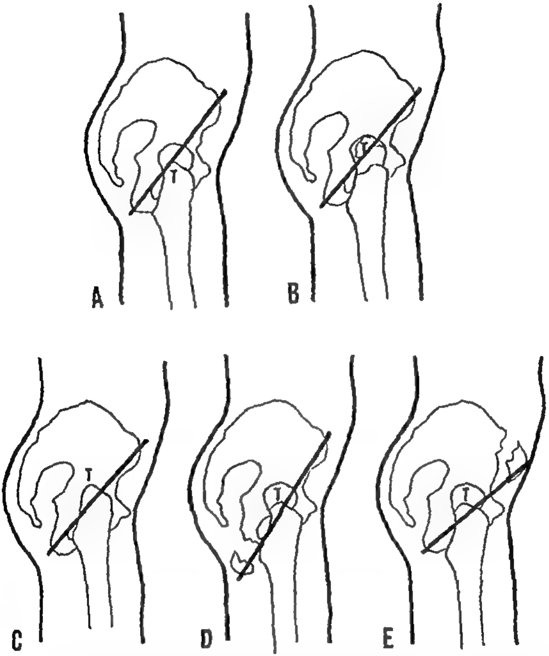


FIG 350 Nelaton's line (*A*) The normal relationships between the anterior superior iliac spine the ischial tuberosity and the tip of the greater trochanter (*T*) with the thigh in extension is indicated The distance from each of these points to the medial malleolus is the same on both sides In the other figures the trochanter lies above Nelaton's line (*B*) A fracture of the greater trochanter The distance from the tip (*T*) to the medial malleolus is greater on this side than the normal side (*C*) Either a dislocation of the femoral head a varus deformity or a fracture of the femoral neck is shown The distance from all three points to the medial malleolus is less than on the normal side (*D*) A fracture of the ischial tuberosity with downward displacement the distance from the tuberosity to the medial malleolus is less than on the normal side The other measurements remain unaffected (*E*) A fracture of the anterior superior iliac spine with downward displacement of the fractured fragment and the distance from this point to the medial malleolus is less than on the unaffected side

Fig 348 Resection angulation operation for nonunited fracture of the femoral neck (*Left*) Nonunion of the femoral neck with beginning avascular necrosis of the head is to be seen The Smith Petersen nail has been improperly inserted (*Right*) The Smith Peterson nail has been extracted and the femoral head and neck excised down to the intertrochanteric line An osteotomy has been performed below the level of the lesser tuberosity the distal fragment has been abducted and the two fragments have been united with an angulated blade plate

Fig 349 Transcervical fracture in an adolescent There is a marked coxa vara deformity at the site of fracture in the femoral neck with healing in malposition This was corrected by a subtrochanteric osteotomy

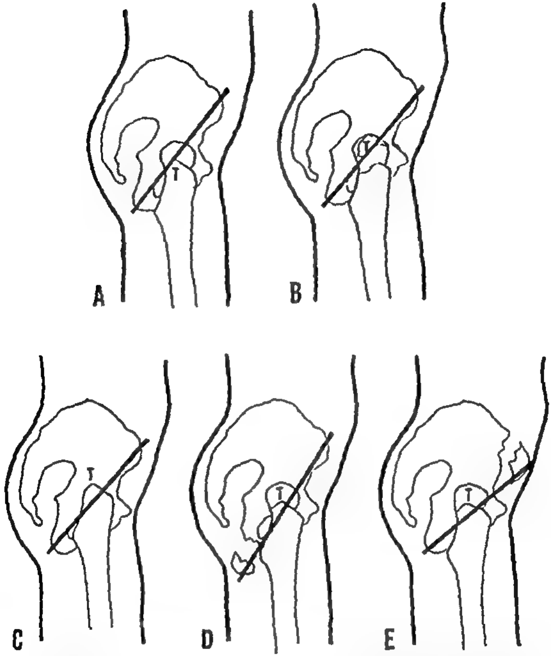


FIG 350 Nelaton s line (*A*) The normal relationships between the anterior superior iliac spine, the ischial tuberosity and the tip of the greater trochanter (*T*) with the thigh in extension is indicated The distance from each of these points to the medial malleolus is the same on both sides In the other figures the trochanter lies above Nelaton s line (*B*) A fracture of the greater trochanter The distance from the tip (*T*) to the medial malleolus is greater on this side than the normal side (*C*) Either a dislocation of the femoral head a varus deformity or a fracture of the femoral neck is shown The distance from all three points to the medial malleolus is less than on the normal side (*D*) A fracture of the ischial tuberosity with downward displacement, the distance from the tuberosity to the medial malleolus is less than on the normal side The other measurements remain unaffected (*E*) A fracture of the anterior superior iliac spine with downward displacement of the fractured fragment and the distance from this point to the medial malleolus is less than on the unaffected side

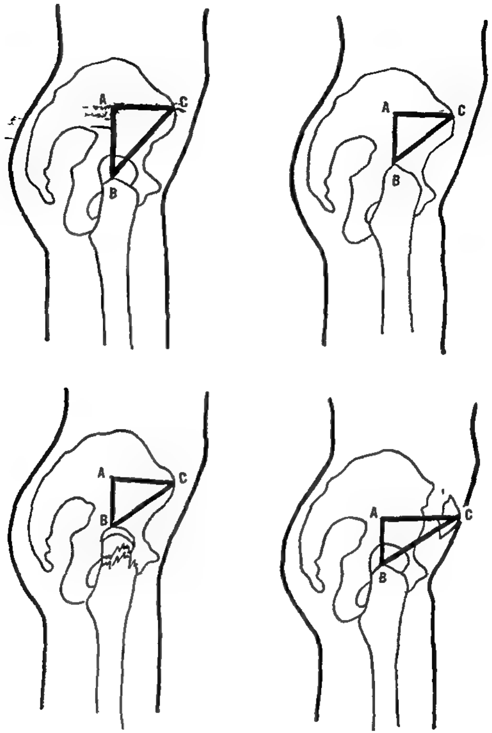


FIG 351 Bryant s triangle (*Upper left*) The distance (*AB*) between the tip of the greater trochanter (*B*) and the base of Bryant s triangle (*AC*) is normal and equal on both sides (*Upper right*) Either a dislocation of the femoral head a varus deformity or a fracture of the femoral neck since distance (*AB*) is shorter than on the normal side The distance from the anterior superior iliac spine to the medial malleolus will be less than on the normal side owing to upward displacement of the limb as a whole The distance from the tip of the trochanter to the medial malleolus however would be

either to arthrodese the hip or to perform a Schanz subtrochanteric osteotomy and thus to complete the resection angulation operation (Figs 348 and 357)

While arthrodesis, when successful, has the merit of relieving pain and affording stability, it has the disadvantage of limitation of motion The Schanz osteotomy has the advantage of re-establishing stability while, at the same time, preserving mobility

TRANSCERVICAL FRACTURES

Transcervical fractures of the femoral neck are usually seen in patients of old or middle age, but they may also occur in young children In the young, they are usually characterized by a coxa vara deformity that is frequently not recognized as an acute fracture until some time after the appearance of the deformity (Fig 349) At that time treatment for the restoration of the angle of the femoral neck can usually be effected by means of a subtrochanteric osteotomy

In adults transcervical fractures are intracapsular, almost always of the adduction type and are characterized clinically by apparent shortening pain on motion, eversion and loss of power in the affected limb A great deal of stress has been laid upon their diagnosis by noting the relationship of the trochanter either to Nelaton s line or to Bryant s triangle Both of these tests are based upon a statement of geometrical relationship that has no value unless the points of reference (ischial tuberosity, greater trochanter, and anterior superior iliac spine) are established as being normally situated either prior to the time of injury or by comparison with the opposite unaffected side Any pre-existing abnormality of the ischial tuberosity, the tip of the greater trochanter, or the anterior superior spine will necessarily lead to a disturbance of these geometrical relationships Unless it can be shown that there is no tilting of the pelvis no change in the distance between the anterior superior iliac spine or the ischial tuberosity and the medial malleolus of the tibia *or no increase in the distance between the tip of the greater trochanter* and the tip of the *medial malleolus, these tests are completely useless* (Figs 350 and 351)

As contrasted with abduction fractures in the subcapital region, where the fracture line is relatively horizontal the fracture line in transcervical fractures is usually oblique and may be completely vertical The treatment and prognosis in these fractures depends to a large degree on the obliquity of the fracture line Pauwels has shown that these adduction fractures may be roughly divided into three

---

unchanged (*Lower left*) A fracture of the greater trochanter The distance (*AB*) is shorter than on the normal side The distance from the greater trochanter to the medial malleolus is greater but the distance from the anterior superior iliac spine to the medial malleolus is unchanged as compared with the normal side (*Lower right*) A fracture of the anterior superior iliac spine The distance (*AB*) is shorter than on the opposite unaffected side as is the distance from the anterior superior spine to the medial malleolus The distance from the tip of the greater trochanter to the medial malleolus however is unchanged

groups, depending upon the angle that the fracture line makes with the horizontal (Pauwels' angle) In those fractures where the angle is thirty degrees or less, the shearing force exerted by body weight is minimal and healing usually occurs after reduction In those in which the angle is from thirty to sixty degrees, the shearing force is greater and internal fixation is essential for adequate healing, while in those in which the angle is greater than sixty degrees, nonunion is likely to occur despite adequate internal fixation (Fig 352)

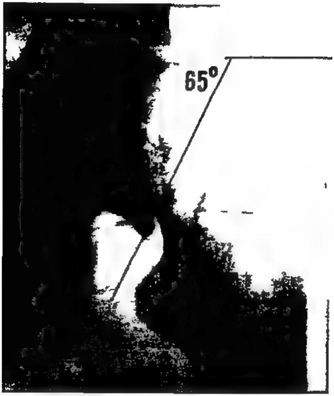


FIG 352 Transcervical adduction fracture The angle which the fracture line makes with the horizontal (*Pauwels angle*) measures sixty five degrees Internal fixation is essential in such cases Because the angle is greater than sixty degrees the prognosis for bony union must be guarded

The first essential in the treatment of these fractures is adequate reduction This must be performed on a fracture table in an operating room fully prepared for the subsequent insertion of internal fixing devices Where there is no upward displacement of the distal fragment gentle traction and internal rotation frequently suffice to secure proper alignment This should be checked roentgenographically and, if satisfactory, the thigh is then abducted to lock the fragments in the reduced position (Whitman maneuver) Abduction should not be undertaken before internal rotation since this prevents reduction

Where there is upward displacement of the distal fragment, the level of the

fracture can be restored either by traction in external rotation or by Leadbetter's maneuver This latter is carried out by flexing the involved thigh to ninety degrees and pulling directly upward using the body as countertraction Following this, the thigh is extended and internally rotated as in Whitman's maneuver and tested for stability The heel is supported in the palm of the hand If there is no tendency toward rotation or upward displacement, satisfactory contact of the fragments may be assumed (Leadbetter's test), and the thigh may then be brought into abduction to lock the fragments The position should be visualized roentgenographically and, if unsatisfactory, the entire maneuver should be repeated

Immobilization of the reduced position may be maintained by means of a plaster of Paris spica, which should extend from well up on the chest wall to and including the foot on the affected side and should extend down to at least the level of the knee on the unaffected side It is impossible to fix the pelvis and thus avoid loss of position by means of a single hip spica The cast method of treatment has the disadvantage that it involves bed rest for from three to six months and prolonged fixation of the knee and ankle with the likelihood of resulting stiffness in these joints It is because of this that methods of internal fixation are to be preferred

Many different types of fixation devices have been used in the treatment of these fractures These include the Lorenzo screw, various types of lag and cork screws, the Smith-Petersen triflanged nail and its various modifications, and Telson wires Each has its proponents, but it really matters very little which device is used to maintain the fracture provided that adequate reduction of the fracture and proper insertion of the device have been accomplished

The simplest method to assure proper direction of the internal fixation device is by the preliminary insertion of a guide wire The extremity, while in abduction, is turned into fifteen degrees of internal rotation This serves to bring the neck of the femur into a plane parallel to the operating table A point midway between the anterior-superior iliac spine and the spine of the pubis is marked on the skin along the course of the inguinal ligament This identifies the position of the acetabulum A small incision is made along the outer aspect of the femoral shaft and at a point about one inch below the base of the trochanter The Kirschner wire is inserted so that it lies in a plane parallel to the table and directed upward and medially toward the previously noted position of the acetabulum If the wire is directed properly, there will be no excessive resistance to its passage until the wire engages the cartilaginous surface of the proximal fragment If resistance is encountered before the wire has been inserted a distance equal to the estimated length of the femoral head and neck (slightly less than the actual measurement of the guide wire against the x ray films), the direction is probably inaccurate and the resistance is due to penetration of the cortex of the neck The wire should be withdrawn and re inserted at a slightly different angle The accuracy of introduction of the guide wire should be checked roentgenographically before any attempt at final fixation If the position is satisfactory, any of the fixing devices that it is desired to employ may be threaded either alongside or over the guide wire and gently hammered or screwed into place The validity of this insertion should again be

controlled by x-ray examination to make certain that the hip joint has not been penetrated (Fig 353)

Where internal fixation is not considered feasible or, having been attempted, has failed owing to the obliquity of the fracture line, subtrochanteric osteotomy, either of the angulational type (Fig 354) or of the transpositional type (Fig 355), may be employed The stability of the osteotomized femoral fragments can be assured by the insertion of a Neufeld nail or of a properly angulated Blount-Moore

FIG 353 Low transcervical fracture of the femoral neck A Smith Petersen triflanged nail has been inserted and passes well beyond the line of fracture

blade plate (Fig 356) While this, in itself, is frequently sufficient to assure stability not only of the osteotomized femur but also of the fracture site, it has occasionally been found that displacement of the proximal fragment occurs To avoid this, a wire or screw should transfix the trochanteric fragment of the osteotomized femur and the fractured capital fragment

By whatever method transcervical fractures are fixed weight bearing should be interdicted for a period of at least three months, though early motion of both the hip and knee is to be encouraged Even at the end of three months weight bearing should not be permitted without the additional support afforded by a Thomas walking caliper Healing in these fractures is notoriously slow and cannot be depended upon for unassisted weight bearing for a minimum period of nine to twelve months postoperatively

FIG 354 Low transcervical fracture of the femoral neck (*Left*) Subtrochanteric osteotomy has been performed above the level of the lesser trochanter The distal osteotomized fragment has been transposed medially and angulated outward so that the fracture line is supported by the upper end of the osteotomized shaft (*right*)

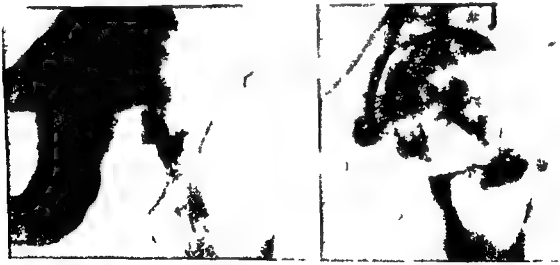


FIG 355 Low transcervical fracture of the femoral neck (*Left*) A subtrochanteric osteotomy has been performed at a level such that when the shaft was transposed medially the fracture line was supported on the upper end of the shaft The exact level for performing osteotomy should be determined by the preliminary insertion of a Kirschner wire so that it lies just at the lowermost portion of the proximal fragment (*right*)

FIG 356 Transcervical fracture of the femoral neck A subtrochanteric transpositional type of osteotomy has been performed The osteotomized fragments of the femur have been fixed by an angulated blade plate

While the alignment of the fracture can be maintained by any of the above described methods none affords any guarantee as to the ultimate outcome In the last analysis the result in fractures of the neck of the femur is determined by the circulation in the proximal fragment There is no way of determining the degree to which this circulation has been impaired either at the time of the original injury or during the subsequent maneuvers of reduction Aseptic, ischemic necrosis and the development of the traumatic arthritis cannot be excluded or forearmed against by any of these purely mechanical efforts Fracture of the neck of the femur has been deservedly called the unsolved fracture not because of any lack of mechanical ingenuity but rather purely because of the inability to evaluate the degree to which circulation in the proximal fragment has been embarrassed

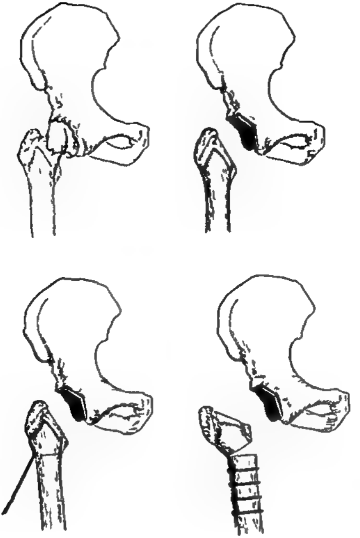


Fig 357 Resection angulation operation The successive stages are (1) exposure of the femoral head and neck through a lateral iliofemoral incision (2) resection of the head and neck if necessary with acetabuloplasty to remove overhanging osteophytes (3) insertion of the previously angulated blade plate and (4) angulational osteotomy of the femoral shaft and fixation of the blade plate (Reprinted from Milch H The resection angulation operation for hip joint disabilities *J Bone & Joint Surg 37A* 699 1955)

Where a disabling arthritis of the hip develops subsequent to fracture, the problem is essentially that of the treatment of painful limitation of hip motion As in other types of arthritis, treatment may be effected by arthrodesis of the joint by arthroplasty or prosthetic replacement, or by the performance of the resection-angulation operation Arthrodesis when successful has the advantage of eliminating pain and affording a stable hip It has the disadvantage, however, of permanent limitation of motion in the affected hip and, in a noteworthy percentage of cases,

leads to intractable pain in the lumbosacral area It is not applicable in those patients in whom there is an arthritis of the opposite hip or limitation of motion in the lumbar spine As a consequence, recourse has been had to various types of arthroplasty or prosthetic replacement of the femoral head Neither of these procedures has proved to be particularly satisfactory in the treatment of traumatic

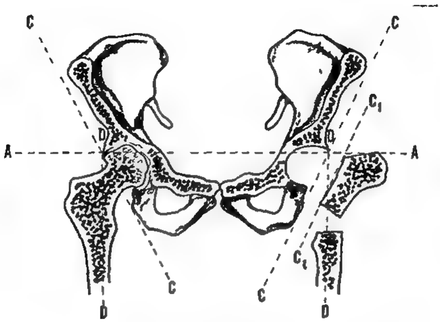


FIG 358 Angle of pelvic wall inclination Any two symmetrical points such as the superior margins of the acetabula (*DD*) are selected and the line through these points (*AA*) is drawn to represent the horizontal The line *CC* is drawn tangent to the point *D* and the most lateral projection of the tuberosity of the ischium The angle of pelvic wall inclination can be measured against the horizontal (*AA*) but is better measured against a line drawn perpendicular to *AA* at the point *D* The larger outward opening angle angle *CDD*, is the angle of pelvic wall inclination On the left side the congruence of the osteotomized femur with the angle of pelvic wall inclination is indicated by the outwardly opening angle formed between the line *CC* and *DD* (Adapted from Milch R A Roentgenographic study of the inclination of the lateral pelvic wall and the interacetabular distance in normal adult pelves *J Bone & Joint Surg 36A* 533, 1954)

arthritis On the other hand the resection-angulation operation which aims at relief of pain with preservation of mobility has proved to be a procedure applicable to all types of arthritis

In principle, the operation consists of a pelvic release operation effected by resection of the femoral head and neck, and a pelvic support operation by means of a Schanz type of subtrochanteric osteotomy (Fig 357) The operation may be

performed in two stages in which event the osteotomy should be performed first Preferably the operation should be completed in one stage The femoral head and neck are resected along the intertrochanteric line through a lateral iliofemoral incision A transverse osteotomy is then performed just below the level of the lesser trochanter and the distal osteotomized fragment is angulated outward (postosteo-

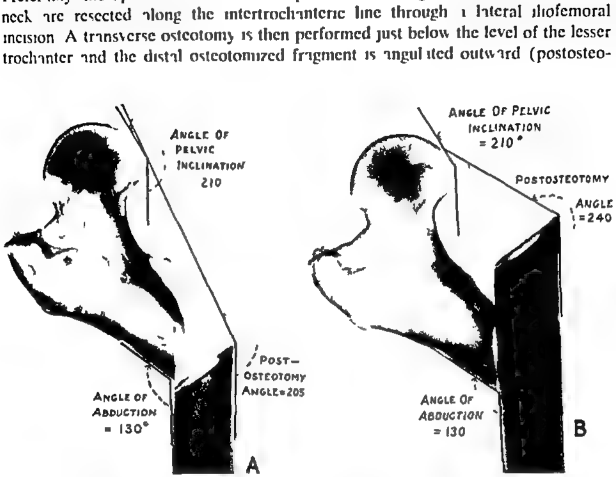


FIG 359 Postosteotomy angle The postosteotomy angle is the neck angle of the osteotomised femur It is determined between a line drawn parallel to the shaft of the distal osteotomised femur and a line from the upper end of the osteotomised femoral shaft tangent to the most medial projection of the proximal fragment It is not identical with the angle of abduction of the distal osteotomised fragment In *A* which represents a Schanz type of osteotomy the angle of abduction is 130 degrees while the postosteotomy angle is 205 degrees In *B* which represents a Lorenz type of bifurcation osteotomy the angle of abduction is 130 degrees but the postosteotomy angle is 240 degrees The postosteotomy angle should be made commensurate with the angle of pelvic wall inclination so that the proximal fragment of the femur can rest against the pelvic wall following osteotomy

tomy angle) (Fig 359) to a degree commensurate with the preoperatively determined angle of inclination of the lateral pelvic wall (Fig 358)

Postoperatively the patient is placed in balanced suspension with the thigh in flexion and active motion is started immediately Weight bearing with the aid of crutches usually is possible within three to six weeks after operation and without any support as soon thereafter as tolerated Particular attention must be directed to maintaining the full range of both flexion and extension in the postoperative

period, during which the relatively lengthened pelvitrochanteric muscles must read just to their altered kinesiology

Partial or pseudofractures of the neck are occasionally seen especially in so called Milkman's syndrome, renal osteodystrophy, or in various nutritional deficiencies (Fig 360)

FIG 360 Transcervical pseudofracture of the femoral neck The fracture line disrupts only the medial cortex of the neck No treatment other than simple cast immobilization until the period of acute pain has subsided is required in such injuries (Courtesy of Dr H Sternberg)

INTERTROCHANTERIC FRACTURES

Intertrochanteric extracapsular fractures are undoubtedly more common in the elderly than are the transcervical or subcapital fractures They are usually spiral and frequently comminuted, involving not only the upper end of the femur, but also the lesser trochanter and the femoral neck This latter involvement is particularly serious and should be assiduously sought for, if necessary by making stereoscopic x rays of the femoral neck Failure to recognize the existence of comminution extending into the neck may completely vitiate internal fixation of such fractures since the comminuted neck affords inadequate purchase for the insertion of any fixing device In this event treatment can be only by means of balanced traction preferably the Russell type (Fig 56) for a usual period of about three months

While fractures in this area almost invariably heal owing to excellence of the blood supply, it is particularly important to maintain abduction of the distal frag-

ment so as to re-establish the angle of the femoral neck Neglect of this detail invariably leads to the development of a coxa vara deformity (Fig 361) It is particularly in such cases that treatment by the well leg countertraction method described by Anderson is especially useful (Fig 60) It permits maintenance of the desired position while, at the same time, avoiding the necessity of prolonged recumbency

Where the integrity of the cortex of the femoral neck is maintained, fixation of the fragments may be accomplished by means of a Smith Petersen nail with a

FIG 361 Intertrochanteric fracture of the femur Patient refused hospitalization and was treated at home by Russell s traction in abduction (*left*) Abduction was not maintained with resulting adduction of the distal fragment and a coxa vara deformity (*right*)

McLaughlin bar attachment (Fig 362), a Johansen nail, or an angulated blade plate (Fig 363)

Although adequate callus is usually formed within three months, early unprotected weight bearing is dangerous and may lead to recurrence of a varus deformity It is unquestionably safer to recommend the wearing of a supporting Thomas walking caliper for a period of six to nine months even though callus may appear to be adequate

In newborn children, a special form of fracture analogous to the type of intertrochanteric fracture seen in adults appears in the form of an *epiphyseal separation* of the *entire upper end of the femur* These usually result from difficult breech presentations and are relatively rare but should be suspected when an infant does not move his thigh normally If recognized they should be treated in flexion in

Fig 362 Intertrochanteric fracture of the femur The fragments are comminuted with detachment of the lesser trochanter Reduction was obtained by traction on the fracture table and the position of the neck and shaft were maintained by a Smith Petersen nail with McLaughlin attachment No effort was made to fix the small trochanteric fragment

FIG 363 Intertrochanteric fracture of the femur Following reduction position was maintained by an angulated blade plate

Bryant s overhead traction (Figs 54 and 55) If unrecognized, they heal by massive deposition of callus and a deformity that usually disappears as the child grows

FRACTURES OF THE TROCHANTERS

Fractures of one or both of the trochanters are not uncommon in association with intertrochanteric fractures of the neck of the femur They usually require no treatment other than that which is directed to the major fracture Isolated fracture of either of the trochanters however is relatively rare

FRACTURES OF THE GREATER TROCHANTER

Fracture of the greater trochanter may arise either as a result of direct blows to the region or as a result of avulsion by the attached gluteal muscles In the former

FIG 362 Intertrochanteric fracture of the femur The fragments are comminuted with detachment of the lesser trochanter Reduction was obtained by traction on the fracture table and the position of the neck and shaft were maintained by a Smith Petersen nail with McLaughlin attachment No effort was made to fix the small trochanteric fragment

such instances there is a separation of the entire trochanter at its epiphysis, with a small fragment of bone from the upper end of the femoral shaft (Fig 365) Separation tends to be minimal and no treatment, other than rest in bed during the period of acute pain is necessary Where there is wide separation of the avulsed epiphysis, open operation and bone suture or fixation by a screw is indicated

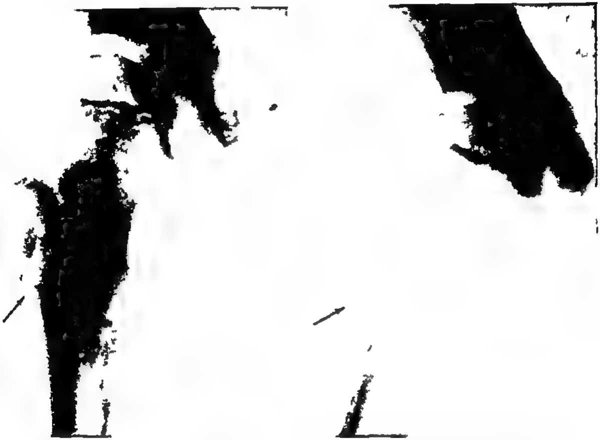


FIG 365 Epiphyseal separation of the greater trochanter The entire trochanter along with a small triangular fragment from the upper end of the femoral shaft has been avulsed (*left*) (*Right*) There is healing by periosteal new bone formation

FRACTURES OF THE LESSER TROCHANTER

Because of its deeply situated position, isolated fractures of the lesser trochanter are almost invariably the result of avulsion by the attached tendon of the iliopsoas muscle They usually occur in adolescents during acts of extreme exertion such as running and jumping and almost always result in a detachment of the entire apophysis of the lesser trochanter Theoretically treatment in flexion adduction and external rotation is indicated to relax the iliopsoas tendon and to approximate the avulsed apophysis to its normal site of attachment In actual practice, however simple bed rest until pain has disappeared and the avoidance of all strenuous activity until firm bony union has occurred suffices to restore normal function (Fig 366)

instance, the fragments may be comminuted in the latter the small proximal fragment is usually solitary (Fig 364) The small fragment tends to be displaced upward and inward, but the displacement usually is of slight degree owing to the fact that the gluteus medius muscle attaches obliquely across the outer surface of the greater trochanter While abduction may be painful and may justify the use of

FIG 364 Isolated fracture of the great trochanter The upper half of the trochanter has been avulsed There is however relatively slight separation of the fragments since the tendon of the gluteus medius muscle straddles the fracture line (Reproduced from Milch H Avulsion fracture of the great trochanter *A M A Arch Surg 38* 334 1939)

immobilization in a plaster of Paris spica in abduction this type of therapy is usually not necessary In most instances, healing takes place without complication, whether or not the patient is immobilized, and normal activity need not be interfered with save for the relief of pain Where there is wide separation of the fragments, it must be presumed that extensive laceration of the tendon of insertion of the gluteus medius muscle has occurred and immobilization in an abduction plaster of Paris spica or preferably open operative intervention to fix the fragment in place is indicated

In children isolated fracture of the greater trochanter takes the form of an epiphyseal separation resulting from avulsion by the gluteus medius muscle In

in the more distal portions of the shaft In subtrochanteric femoral shaft fractures the proximal fragment is short and, under the influence of the iliopsoas the gluteus medius, the obturators the gemelli and the pyriformis muscles, is flexed abducted, and externally rotated The longer distal fragment is pulled into adduction by the adductor group of muscles As a consequence there is a marked varus deformity of the upper end of the femur with outward angulation at the site of fracture,

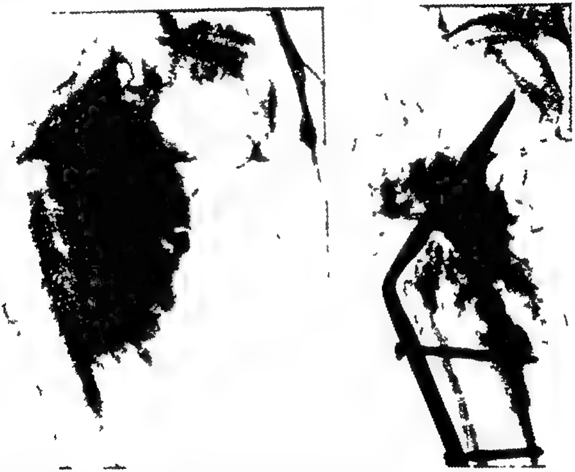


FIG 367 Subtrochanteric fracture of the femoral shaft Early unprotected ambulation was permitted in this case because of the presence of a large amount of callus The varus deformity however promptly recurred (*left*) and could only be corrected at open operation Fixation was performed using an angulated blade plate (*right*)

producing an adduction type of fracture In the more distal fractures displacement is usually that of overriding under the influence of the longitudinally placed quadriceps and hamstring muscles

Treatment of the adduction type of subtrochanteric shaft fracture will in general be that of abduction of the distal fragment so as to bring it into alignment with the abducted proximal fragment The stability of the reduction will depend upon the direction of the line of fracture It has been said that if the fracture line is oblique from above and laterally to below and medially, the reduction will be stable when the distal portion of the limb is brought into wide abduction and

FIG 366 Avulsion fracture of the lesser trochanter The avulsed fragment has been dis placed upward under the action of the iliopsoas muscle No treatment is indicated other than rest preferably with the thigh in flexion and with slight external rotation

FRACTURES OF THE FEMORAL SHAFT

In contradistinction to fractures of the femoral neck in which there is relatively little trauma to the surrounding musculature and in which the therapeutic problem is largely of a mechanical nature fractures of the femoral shaft are characterized by extensive damage to the surrounding musculature a marked internal blood loss and a posttraumatic metabolic response similar in its intensity to that observed following severe third-degree burns The fractures usually arise as a result of severe and violent injuries are frequently comminuted and often compounded They are always acute surgical emergencies threatening limb function and occasionally life

While the observed displacements will naturally depend upon the nature and direction of the fracturing force fractures at the upper end of the femoral shaft in the subtrochanteric region must be clinically differentiated from fractures present

ever, manipulation in combination with traction on the fracture table is frequently successful Where the fracture line is oblique, the reduction is unstable and continuous traction or internal fixation to maintain alignment will be necessary

Continuous traction may be exerted in balanced suspension by skin traction (Fig 368) by skeletal fixation (Figs 50, 52, and 369), or in Russell's traction (Figs 56 and 370), which is specifically designed for fractures of the femoral shaft Balanced suspension has the advantage of permitting motion at the knees by means of the Pearson attachment to the Thomas full ring or Hodgen half-ring splint

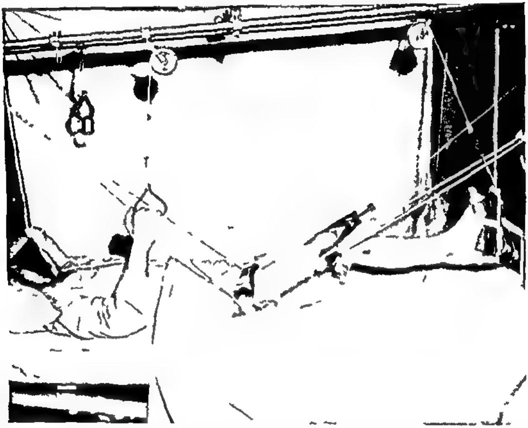


Fig 369 Fracture of the femoral shaft Balanced suspension with skeletal traction A Kirschner wire is inserted through the lower end of the femur and traction is exerted through the bow attached to the wire A Pearson attachment permits motion of the knee

Treatment by means of traction demands constant supervision to avoid distraction and other axial malalignments until there is evidence of callus formation with fixation of the fragments Repeated roentgenograms should be obtained to determine the precise position of the fragments Transpositional malalignments may be corrected by appropriately applied pressure pads attached to the splint and torsion may be controlled either by balanced derotating weights or by fixing the foot to a footpiece that is, in turn, fixed to the splint

Where the prolonged hospitalization that traction necessitates is contraindicated because of extramedical considerations immobilization of the reduced fracture may

immobilized in a plaster of Paris spica Conversely, it has been held that where the fracture line is oblique from below and laterally to above and medially the fracture is unstable and the tendency toward medial displacement of the distal fragment must be combated by continuous traction in abduction

The essential element in the treatment of these fractures is the maintenance of alignment either in a spica with or without traction or by means of the well leg countertraction method of Anderson These fractures are particularly well adapted to internal fixation by means of an angulated blade plate, which is applicable even

FIG 368 Fracture of the femoral shaft Balanced suspension with skin traction and a Pearson attachment to permit motion at the knee

in cases of malunion with recurrence of the adduction deformity (Fig 367) Blade plate fixation has the advantage over immobilization in a spica or by the well leg countertraction method in that it permits early motion both of the hip and of the knee Weight bearing should not be permitted however without the support of a Thomas walking caliper even after three months when union appears to be satisfactory by reason of the abundant callus that invariably forms To avoid the possible recurrence of a varus deformity, the caliper should be worn for an additional period of from three to six months

In *diaphyseal fractures* of the femoral shaft treatment must be directed primarily to correction of overriding and the prevention of angulational or torsional malalignments Overriding may be corrected by manipulation or traction Where the fracture line is transverse manipulation and apposition of the opposed fractured surfaces to at least fifty per cent of their area are usually sufficient to accomplish correction of overriding If this cannot be achieved by simple manipulation how

FIG 371 Fracture of the femoral shaft Medullary nailing assures excellent alignment and permits constant bony contact

treatment of fractures in general to the neglect of older, equally satisfactory methods There can be no objection to the use of skeletal fixation, but it should be employed in selected cases rather than as a routine procedure Intramedullary nailing is the method of choice in multiple or severely comminuted fractures of the midportion of the femoral shaft (Fig 372)

Preoperatively, the distance from the the trochanter to the level of the adductor tubercle is measured and the diameter of the medullary cavity is estimated from the roentgenogram On the average a nail of about 1 0 cm outside diameter usually

be obtained by transfixing each fragment by at least two Steinman pins that can then be incorporated in a plaster of Paris spica

Where even so trivial an operative intervention as by transcortical pins is contraindicated overriding in a long spiral fracture may be avoided by the unorthodox procedure of immobilizing the fracture in an angular deformity This must be corrected after about two weeks when early callus formation may be expected

Where prolonged bed rest is contraindicated, open operation and fixation of the fragments may be undertaken by means of long metallic plates preferably with

FIG 370 Fracture of the femoral shaft Russell s traction with skeletal traction exerted through the upper end of the tibia has been employed

slotted holes so as to permit the maintenance of bony contact without loss of alignment

Delayed or nonunion is a not uncommon complication of femoral shaft fractures treated in this manner Delayed union is usually the result of inadequate immobilization of the fragments and indicates the need for continued immobilization Operative intervention should not be undertaken until there is unequivocal roentgen and clinical evidence confirming the presence of nonunion In some instances fixation by metallic plates even of slotted types has been considered the proximate cause of the nonunion and it is because of this that intramedullary fixation is often a more desirable initial method of treatment (Fig 371) It must be stressed however, that there has been far too much surgical intervention in the

fragment that has been exposed by a lateral incision placed directly over the level of the fracture site The medullary nail is visually guided into the medullary cavity of the distal fragment and should extend down to the level of the adductor tubercle A small portion of the nail is left protruding beyond the trochanter to facilitate extraction if necessary Control roentgenograms should be made to ascertain that

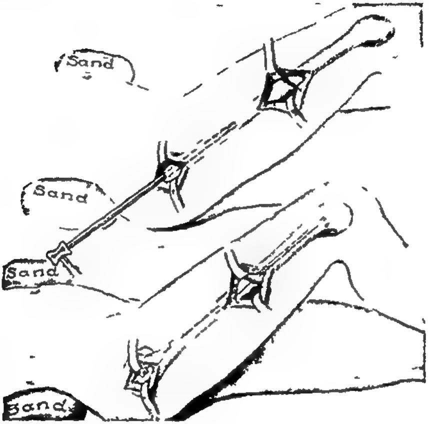


FIG 373 Intramedullary nail fixation for fractured femoral shaft A small incision is made over the tip of the trochanter and the fracture site is exposed The nail is driven into the proximal fragment and guided into the medullary canal of the distal fragment under direct vision (Reproduced from Deyerle W M Medullary nailing in fractures *Clin Orth* 2 53 1953)

there are no angulational or torsional deformities and that the lower end of the nail does not penetrate into the knee joint

Postoperatively, the patient may be permitted to be ambulatory with the aid of crutches as soon as the postoperative reaction has subsided Early weight bearing should be avoided until there is evidence of solid union Weight bearing begun too early predisposes to bending or even fracture of the nail When there is evidence of union weight bearing may be gradually resumed with the aid of a Thomas walking caliper The nail may be left in place permanently or may be withdrawn when there is evidence of firm bony union

FIG 372 Comminuted fracture of the femoral shaft (*Left*) Intramedullary nailing served to realign the fragments and to re establish length The encircling wire band which was used to maintain the fragments in apposition about the nail is broken and serves no purpose (*right*)

allows firm fixation and easy passage through the medullary cavity of both fragments

The patient is placed in the lateral position lying upon the unaffected thigh with the injured extremity up A small incision is made directly over the greater trochanter and a hole of appropriate size is drilled through the cortex of the trochanter and into the medulla of the proximal fragment (Fig 373) The selected nail is then driven downward until it appears at the lower end of the proximal

As in other fractures of the femur, weight bearing without the use of a Thomas walking caliper should not be undertaken for an additional period of at least three and preferably six months

In attempting to restore mobility of the knee which is frequently diminished during the period of long immobilization care must be taken to avoid undue stress

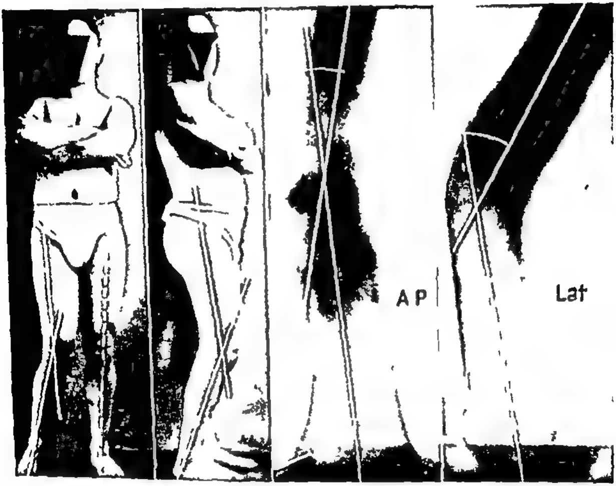


FIG 374 Malunited fracture of the femoral shaft There is anterior bowing as well as abduction of the distal fragment so that the patient has excessive bowing of the femur and valgus of the leg (Reproduced from Milch H Splintering subperiosteal osteotomy for malunited fracture of the femur *J Bone & Joint Surg 11* 562 1929)

at the fracture site It is frequently wiser to release the quadriceps by open operation than to exert excessive forces in flexion of the knee

In children fractures of the femoral shaft present a special problem Under the age of six years before downward tilting of the pelvis and the acquisition of the lumbar lordosis have occurred traction in extension invariably leads to forward angulation at the site of fracture Since any form of skeletal fixation is contraindicated in children fractures in such patients must be treated by traction in the overhead position as described by Bryant (Fig 54)

Skeletal or intramedullary fixation tends to minimize the possibility of union in malposition Malunion may occur, however, under both forms of treatment and may present serious problems that will depend not only upon the nature of the malalignment but also on the antecedent history of compounding or existing infection If prior infection has existed, no attempt at correction of malposition should be undertaken for a period of at least six months after all signs of the infection have completely subsided The use of antibiotics in both early and late treatment of infected fractures has materially reduced the likelihood of reinfection, but is no guarantee that a latent infection may not be reactivated Where the question is entirely one of malposition, treatment will depend upon the nature of the malalignment

The correction of shortening is particularly fraught with danger because of contracture of the adjacent soft tissues and the relative shortening of the neurovascular structures Especially in the elderly, the correction of this type of malalignment which implies the necessity of complete section of the bone with subsequent traction, may lead to neurovascular impairment that may threaten the integrity of the limb Moreover, complete section of the bone re establishes the situation of the original fracture, with all of its attendant possible complications In the treatment of angulational transpositional or torsional malalignments, these dangers may be minimized by the performance of a subperiosteal splintering osteotomy

Splintering osteotomy is performed by stripping the periosteum away from a portion of the circumference of the bone with longitudinal splitting of the bone over the site of the malposition with an osteotome This results in the formation of numerous interlocking fragments of bone that restores mobility at the traction site and under traction and molding at the time of the procedure permits of adequate realignment without loss of bony contact Postoperatively, the fragments may be maintained in position either by traction or by transcortical pin fixation in a plaster of Paris spica While the alignment may not always be anatomical, aesthetic correction of the deformity with the re establishment of effective functional alignment can almost always be obtained (Figs 374 and 375)

Where frank nonunion has occurred intramedullary fixation may occasionally serve to re-establish the continuity of the bone Most frequently however, satisfactory outcome can be assured only by the application of a massive onlay bone graft (Fig 65) The medullary cavities of both ends of the fractured bone should be opened the fracture realigned and held in place by bone-holding forceps while the massive onlay graft is fixed to each of the fragments by at least two screws sufficiently long to penetrate the graft and the opposite cortex The defect between the bone ends should be packed with cancellous bone preferably of autogenous origin and obtained from the region of the posterolateral aspect of the ilium where the supply of bone is more plentiful In removing these grafts particular care must attend the preservation of the inner table of the ilium so as to prevent postoperative herniation The limb should be immobilized in balanced suspension or in a plaster of Paris spica for a period of at least three months at which time complete healing may be expected to have occurred

To avoid the dangers of circulatory embarrassment that this type of overhead traction may precipitate, effective traction with the proximal fragment in flexion may be accomplished by a modification of Bryant's method (Fig 55)

A padded plaster of Paris trunk cast is applied in which is incorporated a bar at right angles to the trunk Traction is made against the end of this bar through

Fig 376 Femoral shaft fracture in an infant Slight overriding and adduction of the upper fragment (*left*) have resulted in abundant callus formation with effective restoration of the axial alignment of the femur (*right*)

Buck's extension strips attached to the leg This portable type of Bryant's traction permits change of position of the child, facilitates nursing care, and obviates hospitalization The child should be maintained in the traction apparatus for a period of six to eight weeks until there is evidence of adequate callus formation Overriding of as much as one inch and even slight axial malalignment may be overlooked in children since the deformity tends to be corrected during the process of remodeling and growth (Fig 376)

nor the lateral angulation has been completely corrected but the axes of both fragments are parallel so that clinically the normal configuration of the limb has been restored Same patient as Fig 374

Fig 375 Malunited fracture of the femoral shaft Splintering osteotomy has been performed Neither the bowing

Reduction is impossible without releasing tension on the gastrocnemius muscle, which acts as the motivating force to cause displacement of the distal fragment. Mere relaxation of the gastrocnemius muscle, however, does not act to effect reduction. Reduction must be attained under anesthesia on the fracture table by manipulation and with traction applied to the leg. If end-to end apposition can be obtained, position can be retained by simple immobilization in a plaster of Paris spica that extends from the trunk at least to below the level of the knee, with the knee in flexion.

If end to-end apposition cannot be attained by this method, it may be necessary to insert a Steinmann pin into the upper end of the distal fragment so that an upwardly directed force may be exerted against the distal fragment, while either skeletal or skin traction is maintained on the leg with the knee in flexion. Downward countertraction exerted through a sling over the lower end of the proximal fragment may or may not be necessary. Once satisfactory alignment has been obtained, the limb may be immobilized in a plaster of Paris spica incorporating the transfixing pins. Where pins are used, they may be removed after four or five weeks, but immobilization should be continued until satisfactory union has occurred, usually within three months.

As in fractures of the femoral shaft, marked stiffness of the knee may result and particular care must attend any efforts at restoration of knee joint function. Excessive manipulative force may lead either to refracture of the femur or fracture of the patella. Manipulation of the knee joint is a serious procedure and where the likelihood of success is judged to be minimal, it is safer to perform operative quadriceps lengthening rather than closed manipulation.

Separation of the Lower Femoral Epiphysis

Epiphyseal separation at the lower end of the femur is a relatively rare injury. It occurs under the age of twenty years, when the epiphysis unites with the remainder of the bone. Formerly it was called wagon-wheel fracture because it most frequently occurred as the result of the shearing force exerted when the leg was caught in the spokes of a revolving wheel. It may, however, occur as the result of direct blows or falls. The displacement of the epiphyseal fragment has been described as being characteristically forward. This is, however, not invariably the case (Fig. 378) and the displacement in all probability depends upon the direction of the fracturing force.

Manipulative reduction is possible only when the patient is seen relatively early after injury. Callus formation occurs rapidly and makes manipulative reduction almost impossible several weeks after the initial injury. When employed, manipulation should be attempted only under rigorous roentgenographic control. If the displacement was anterior before reduction, immobilization should be accomplished with the knee in flexion, even as much as ninety degrees. If, however, the displacement was originally posterior, retention of the reduced separation may be with the knee in extension (Fig. 379). Immobilization should be continued for a

FRACTURES OF THE LOWER END OF THE FEMUR

Fractures at the lower end of the femur may be either supracondylar inter condylar or condylar In children the supracondylar fracture occasionally appears in the form of an epiphyseal separation of the lower femoral epiphysis

Supracondylar Fractures

Supracondylar fractures are infrequent and arise in consequence of severe blows or falls from heights Their treatment is complicated by the fact that as a

Fig 377 Supracondylar fracture of the femur The distal fragment is rotated backward and down ward Reduction was obtained in fair position by manipulation and fixation was accomplished by im mobilization in a long leg plaster of Paris cast with the knee in slight flexion

result of the attachment of the gastrocnemius muscle the small distal fragment is almost invariably *rotated backward and downward (Fig 377) The possibility of* damage to the popliteal artery must always be envisaged No attempt at any manipulative reduction should be undertaken until the status of the distal circulation has been *appropriately ascertained Efforts at manipulation must* be *correspond ingly* gentle

Reduction is impossible without releasing tension on the gastrocnemius muscle, which acts as the *motivating* force to cause displacement of the distal fragment. Mere relaxation of the gastrocnemius muscle, however, does not act to effect reduction. Reduction must be attained under anesthesia on the fracture table by manipulation and with traction applied to the leg. If end to end apposition can be obtained, *position* can be retained by simple immobilization in a plaster of Paris spica that extends from the trunk at least to below the level of the knee, with the knee in flexion.

If end-to-end apposition cannot be attained by this method, it may be necessary to insert a Steinmann pin into the upper end of the distal fragment so that an upwardly directed force may be exerted against the distal fragment, while either skeletal or skin traction is maintained on the leg with the knee in flexion. Downward countertraction exerted through a sling over the lower end of the proximal fragment may or may not be necessary. Once satisfactory alignment has been obtained, the limb may be immobilized in a plaster of Paris spica incorporating the transfixing pins. Where pins are used, they may be removed after four or five weeks, but immobilization should be continued until satisfactory union has occurred, usually within three months.

As in fractures of the femoral shaft, marked stiffness of the knee may result and particular care must attend any efforts at restoration of knee joint function. Excessive manipulative force may lead either to refracture of the femur or fracture of the patella. Manipulation of the knee joint is a serious procedure and where the likelihood of success is judged to be minimal, it is safer to perform operative quadriceps lengthening rather than closed manipulation.

Separation of the Lower Femoral Epiphysis

Epiphyseal separation at the lower end of the femur is a relatively rare injury. It occurs under the age of twenty years, when the epiphysis unites with the remainder of the bone. Formerly, it was called wagon-wheel fracture because it most frequently occurred as the result of the shearing force exerted when the leg was caught in the spokes of a revolving wheel. It may, however, occur as the result of direct blows or falls. The displacement of the epiphyseal fragment has been described as being characteristically forward. This is, however, not invariably the case (Fig. 378) and the displacement in all probability depends upon the direction of the fracturing force.

Manipulative reduction is possible only when the patient is seen relatively early after injury. Callus formation occurs rapidly and makes manipulative reduction almost impossible several weeks after the initial injury. When employed, manipulation should be attempted only under rigorous roentgenographic control. If the displacement was anterior before reduction, immobilization should be accomplished with the knee in flexion, even as much as ninety degrees. If, however, the displacement was originally posterior, retention of the reduced separation may be with the knee in extension (Fig. 379). Immobilization should be continued for a

FIG 378 Lateral and anteroposterior views of separation of the lower femoral epiphysis Outward and backward dislocation of the distal femoral epiphysis that followed a clipping injury in a football game

FIG 379 Separation of the lower femoral epiphysis Postreduction result of patient of Fig 378 The separation was reduced manually under x ray control and the reduction was maintained with the leg in extension

period of four to six weeks after which gentle active motion of the knee may be instituted Weight bearing should be avoided for several weeks thereafter

If accurate anatomical alignment is impossible or if union has occurred in malposition open operation for reduction of the fragments is necessary In all injuries at the epiphyseal line skeletal fixation that bridges the epiphysis is to be avoided

FIG 380 Separation of the lower femoral epiphysis Because of the existence of the femoral shaft fracture the epiphyseal separation at the lower end of the femur was overlooked (*left*) with resulting premature closure of the epiphyseal plate and the development of a marked genu valgum (*right*) (Courtesy of Dr J Milgram)

since it leads to premature closure of the epiphyseal plate, inequality of growth and subsequent deformity (Fig 380)

Intercondylar Fractures

Intercondylar fractures are usually comminuted The fracture line may be Y- or T-shaped and invariably extends into the joint, which is characteristically tensely distended by a hemorrhagic effusion This should be aspirated under aseptic pre-

cautions before any effort at reduction is made Where there is but little displacements of the fragments, immobilization by means of a plaster of Paris spica with the knee in flexion until healing is complete usually suffices Separation and marked displacement of the fragments results from impaction of the upper fragment between the portions of the distal fragments In such event, traction is necessary both to restore length and to withdraw the distal end of the upper fragment so as to permit of reduction This is usually accomplished by skeletal traction exerted

Fig. 281 Comminuted intercondylar fracture of the lower end of the femur This fracture was treated by skeletal traction for a period of eleven weeks without any change in alignment (*left*) Satisfactory reduction was obtained at open operation and position was maintained by insertion of an angulated blade plate (*right*)

through a pin or wire inserted into the upper end of the tibia at the level of the tibial tubercle This type of traction exerts its effects through tension on the capsular ligaments which are attached to the lower end of the fractured fragments Excessively prolonged traction of this nature may result in stretching of the capsular

FIG 382 Comminuted intercondylar fracture of the lower end of the femur Reduction was obtained by *traction on the fracture table* The position was maintained by insertion of an angulated blade plate

cautions before any effort at reduction is made Where there is but little displacements of the fragments, immobilization by means of a plaster of Paris spica with the knee in flexion until healing is complete usually suffices Separation and marked displacement of the fragments results from impaction of the upper fragment between the portions of the distal fragments In such event, traction is necessary both to restore length and to withdraw the distal end of the upper fragment so as to permit of reduction This is usually accomplished by skeletal traction exerted

Fig 381 Comminuted intercondylar fracture of the lower end of the femur This fracture was treated by skeletal traction for a period of eleven weeks without any change in alignment (*left*) Satisfactory reduction was obtained at open operation and *position* was maintained by insertion of an angulated blade plate (*right*)

marked over a considerable area of the lower end of the femur, fixation of the fragments may be accomplished by the insertion of an angulated blade plate similar to that used at the upper end of the femur, but in which the angles have been modified to conform with the configuration of the lower end of the femur (Fig 382)

Although the application of this type of skeletal fixation may be exceedingly difficult it has the definite merit of permitting early mobilization of the affected knee joint postoperatively The extremity may be supported in simple balanced suspension with a Pearson attachment that permits motion at the knee Where balanced suspension is not desirable the limb may be immobilized in a plaster of Paris cast, as in the treatment of nondisplaced intercondylar fractures

Fig 384 Longitudinal fracture of the medial femoral condyle There was only slight displacement of the fragment and treatment consisted of immobilization in a long leg plaster of Paris cast with the knee in slight flexion

ligaments This should be avoided, since the ultimate result is a lax knee joint If reduction cannot be obtained within two to three weeks, other means of accomplishing the reduction should be undertaken (Fig 381)

After traction has been applied so that relative length of the limb has been restored, reduction of the widening of the knee joint resulting from diastasis of the fragments may be accomplished either by manual pressure or by the use of a carpenter s clamp If successful the limb should be supported in balanced suspension while skeletal traction is maintained on the leg Traction is usually necessary for a minimum period of four to six weeks after which the traction pins may be removed and skin traction may be substituted for an additional period of about four weeks Quadriceps exercises to maintain the tone of this muscle should be instituted from the very outset, but active motion should not be undertaken until there is satisfactory roentgen evidence of union Weight bearing with a Thomas walking caliper may be permitted after this and should be continued for an additional two to three months

If satisfactory alignment of the fracture cannot be obtained by traction methods open operation should be performed In this circumstance the reduced position may be maintained by wires, bands, bolts, or screws Where the comminution is

FIG 383 Fracture of the lateral femoral condyle The fragment consisting of the posterior half of the articular surface of the condyle could not be reduced and was later removed

FIG 386 Ski point Parosteal calcification of the tibial collateral ligament resulting from ski injuries must be carefully differentiated from avulsion fractures of the adductor tubercle

FIG 385 Osteochondral fracture of the lateral condyle The small fragment acted as joint mouse and was removed after arthrotomy of the knee joint

CONDYLAR FRACTURES

Condylar fractures are exceedingly rare and may vary from small isolated fragments that are shorn off the articular surface of the condyle to vertical fractures involving almost all the condyle and extending into the joint (Fig 383) In the larger fragments the fracture line is usually longitudinal (Fig 384) Reduction should be attempted by manipulation but if unsuccessful, open operation with skeletal fixation by means of a screw bolt or angulated blade plate is indicated Anatomical reposition is essential since the fractures are intraarticular and unless perfectly reduced lead to a traumatic arthritis of the knee joint Where the fragment is small, it may act as a free body (joint mouse) and should be removed (Fig 385)

Avulsion fracture of the adductor tubercle occurs but infrequently and must be differentiated from parosteal calcifications that are seen after injuries to the tibial collateral ligament (ski point) (Fig 386)

moid bone developed within the extensor apparatus of the knee joint and that such fractures as lead to a loss of continuity in the extensor apparatus lead to inability to extend the knee This however, applies only to those transverse fractures in which there is actual loss of continuity in the extensor apparatus Other fractures of the patella that do not lead to such a loss usually result in little inconvenience and require but minimal treatment

Although the existence of patellar fractures may be suspected clinically accurate diagnosis is possible only by means of the x-ray Routine roentgenography of the patella involves the making of standard anteroposterior and lateral views along with a special tangential view

This special tangential view is made with the patient lying in the prone position and with the affected knee flexed to about twenty degrees less than a right angle

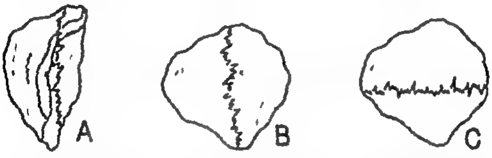


FIG 388 Types of patella fractures *A* The clamshell type in which the plane of fracture is more or less parallel to either the posterior or anterior surfaces of the patella *B* Longitudinal type in which the fracture line is perpendicular to the anteroposterior surfaces *C* The transverse type in which the fracture line is perpendicular to the longitudinal axis of the patella

(seventy degrees) The x-ray tube is tilted so that its central beam is parallel to the posterior surface of the patella This serves to project the anterior and posterior surfaces of the patella on to the x-ray plate beyond the most distal point of the femur (Fig 387) By this method, the anterior and posterior surfaces of the patella are visualized

Fractures of the patella may be divided into three main groups the tangential (clamshell) type *A* the longitudinal type *B* and the transverse type C (Fig 388)

Tangential Fractures

The tangential or clamshell type of fracture is characterized by the fact that the plane of fracture is more or less parallel to the anterior or posterior surfaces of the patella The continuity of the extensor apparatus is not disturbed and frequently the fracture itself cannot be demonstrated except by the tangential view of the patella

Owing to the compressive action of the extensor apparatus, separation between the fragments is usually slight and there is no need for reduction Because there is no loss in the continuity in the extensor apparatus immobilization in a long leg

CHAPTER 20

Fractures of the Patella

Because of its subcutaneous position, fractures of the patella are fairly common in adult life They may result from direct blows or indirectly in consequence of force exerted by the quadriceps femoris tendon against the restraining influence of the

FIG 387 Tangential view of the patella The knee is flexed to about seventy degrees and the central beam of the x ray is directed down ward parallel to the posterior surface of the patella

patellar tendon *Fractures that result from direct trauma are more likely to be* comminuted or stellate in character while indirectly caused fractures tend to present transverse fracture lines

The importance of these injuries arises from the fact that the patella is a sesa

central fractures may appear more important because of the size of the fragments and the possibility of a late traumatic arthritis the smaller marginal fractures are more apt to give rise to chronic symptomatology

Central longitudinal fractures are associated with severe hemarthrosis and repeated aspiration of the bloody synovial fluid is necessary Because of the fact that the tendon of the quadriceps muscle attaches to both of the fragments, the continuity of the extensor apparatus is not interrupted and contraction of the muscle tends to approximate the fragments As a consequence, reduction is frequently

FIG 390 Marginal longitudinal fractures of the patella In the tangential view marginal fracture of the medial edge which cannot be seen in the anteroposterior view is seen to be associated with a marginal fracture laterally

unnecessary and immobilization is indicated primarily for the control of pain Weight bearing and normal use of the knee may be permitted as soon as pain has subsided This tends to reduce the amount of callus that is normally minimal because of the close approximation of the fragments (Fig 389) Where there is extensive comminution without loss of extensor power it may be better to permit healing and then if necessary to remove that portion of the posterior surface which is incongruous with the femoral condyles, rather to undertake primary excision of fragments

Marginal longitudinal fractures (Fig 390) frequently result in nonunion because of the distorting action of the vastus muscles that attach to either side of the patella These fractures, particularly when seen late may resemble a con-

cast with the knee in extension is necessary only during the period of acute pain Thereafter, weight bearing and motion within the limits of pain may be permitted The most pressing indication is for the treatment of the hemarthrosis that is a con stant feature of all injuries to the internal structures of the knee Failure to relieve the internal tension by repeated aspiration leads to infiltration with blood and relaxation of the intrinsic ligaments, a disability far more serious than that due to the fracture

Longitudinal Fractures

Longitudinal fractures of the patella are usually visible on a routine antero posterior roentgenogram The fracture line may be central or marginal While the

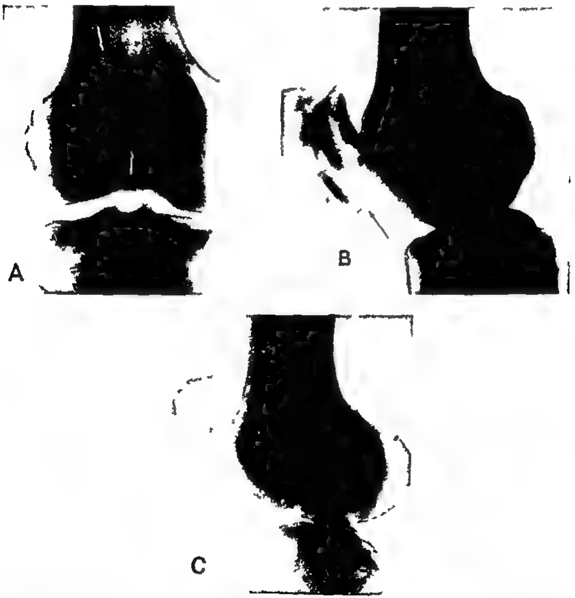


Fig 389 Comminuted central longitudinal fracture of the patella (*A*) *The* central fracture line is indicated by the arrow The lateral view (*B*) shows that there has been some comminution of the lower fragment The fracture was easily reduced and accurately approximated by suture of the periosteal covering of the patella (*C*)

Fig 392 Transverse fracture of the lower pole of the patella There is but little separation of the fragment and treatment with complete recovery was by simple immobilization with the knee in extension

Fig 393 (*Left*) Transverse fracture of the mid portion of the patella There is wide separation of the fragments

Fig 394 (*Right*) Transverse fracture of the mid portion of the patella Open operation was performed to suture both the bone and the patellar retinaculum

genitally bipartite patella The differentiation may be made by comparison of the x ray with that of the unaffected knee In either event, the persistence of pain *represents a justifiable indication for removal of the small fragment* with subsequent reattachment of the detached vastus muscle to the patellar margin

Transverse Fractures

Transverse fractures may occur at either pole (Figs 391 and 392) or through the center of the body (Figs 393 and 394) Fractures of the upper pole are relatively infrequent while fractures at the lower pole are much more common Following direct trauma however multiple fragments producing the so-called stellate type of fracture are most common

FIG 391 Transverse avulsion fracture of the upper pole of the patella Avulsion of the small fragment of the upper pole has occurred as a result of traction by the quadriceps femoris muscle This patient was treated by simple cast immobilization with an excellent result

Transverse fractures of the patella differ entirely from the other types in the essential fact that they involve a loss of continuity of the extensor mechanism The unopposed action of the quadriceps muscle pulls the proximal fragment upward and separations of three or more inches between the fragments have been seen Though a hiatus of such size can be repaired by fibrous connective tissue with

FIG 396 Transverse fracture of the lower third of the patella Accuracy of both anterior and posterior surfaces was achieved by the insertion of a vertical mattress wire suture The patellar retinaculum was reconstituted by two layers of interrupted sutures

FIG 397 Transverse fracture of the lower third of the patella Inaccurate reduction and healing in malposition were followed by pain and limitation of motion of the knee joint owing to the development of a traumatic arthritis A piece of broken needle is seen at the lower pole of the patella

restoration of normal knee function, the probability is slight and should not dis parage the effort to secure a more prompt and more assured result by bony union

Where the condition of the patient is such as to contraindicate open reduction and where there has not been too extensive a laceration of the soft tissues, the proximal fragment may be held in place by encircling adhesive strips while the action of the quadriceps may be minimized by immobilizing the entire limb in a plaster of Paris cylinder with the knee in complete extension The plaster of Paris cylinder should extend from the upper part of the thigh to well down toward the ankle joint and should be left in place for a minimum period of four weeks After this the cast may be removed and a posterior molded splint substituted, which

Fig 395 Transverse fracture of the lower pole of the patella Treated by open operation and bone suture with chromic catgut

will permit the beginning of quadriceps exercises without concomitant motion of the knee joint At the end of about six weeks gentle attempts at active flexion may be permitted, and the patient may be started on weight bearing with the posterior splint in place Gradual increase of flexion may be encouraged and after about eight weeks the patient may be permitted to walk about without the posterior splint Inadvertent forcible flexion of the knee should be forewarned against by the use of crutches or a cane during walking

Full restoration of flexion at the knee may be prolonged beyond this minimum period Usually though not always flexion is eventually completely restored This method is more apt to be successful where there is no separation of the fragments Where separation of the fragments occurs laceration of the patellar retinaculum must be predicated and open operation is the therapeutic method of choice

Operative intervention involves two different procedures (1) bone suture and (2) repair of the patellar retinaculum Exposure of the fracture site should be

Probably the most important single factor in maintaining the reduction obtained is careful suture of the patellar retinaculum, which is almost invariably lacerated widely to each side of the bone Simple suture of the retinaculum is in itself frequently sufficient to afford excellent apposition of the fragments and to assure their retention It should always be repaired in two layers

After skin closure, the extremity should be immobilized with a plaster of Paris cylinder extending from the upper thigh to just above the ankle with the knee joint in extension Ambulation with weight bearing may be permitted almost immediately after operation The plaster cast may be removed after ten days to two weeks and gradual active and passive exercises may be instituted Full use of the limb should be interdicted, however, until there is roentgenographic evidence of bony union

undertaken through either lateral or superior curved incisions Transverse or longitudinal incisions over the patella are best avoided After retraction of the skin and exposure of the fracture, the joint should be carefully flushed with warm saline to evacuate the large blood clots In recent fractures, the bone fragments can be readily approximated by sharp retractors or towel clips It is more important to assure accurate alignment of the posterior surfaces of the patellar fragments than of the anterior surfaces Unfortunately, the posterior surface is not as readily

Fig 398 Comminuted stellate type fracture of the patella The posterior surface of the patella is irregular owing to malposition of the fragments (*left*) Complete excision of the patella was performed with satisfactory restoration of function (*right*)

accessible as the anterior and excessive irregular callus formation is the rule rather than the exception

Where the patella is divided into a large main fragment and a small inferior, polar fragment irregularity or excessive callus formation at the site of union is not apt to traumatize the cartilage of the femoral condyle The fragments may be united either by heavy chromic or wire suture (Figs 395 and 396) If, however the fracture line occurs at a level where irregular or excessive callus may traumatize the articular surface of the femur, and thus lead to a traumatic arthritis (Fig 397), removal of the fragment with resuture of the patellar tendon is to be preferred to any attempts at bone suture

In cases of *comminuted or stellate fracture* where it is possible accurately to reduce the fragments bone suture may be attempted If, however, the comminution is great and the multiplicity of small fragments makes bone suture impossible, it is unquestionably better practice to remove the fragments, or even the whole patella rather than to jeopardize function of the knee by a prolonged and not infrequently fruitless effort to secure bony union (Fig 398)

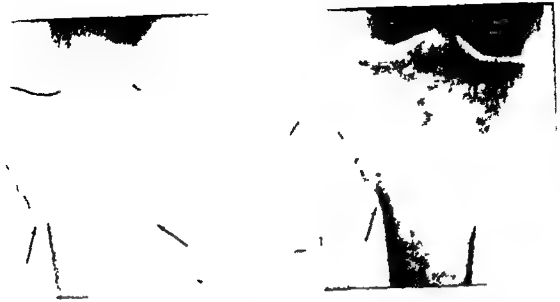


FIG 399 Bumper fracture of the tibia There is a comminuted bicondylar fracture of the upper end of the tibia extending into the knee joint (*left*) There is slight widening of the upper end of the tibia but relatively little displacement of the fragments in relation to each other Uneventful healing followed simple immobilization in a plaster of Paris cast (*right*)

FIG 400 Bumper fracture of the upper end of the tibia There is marked comminution with widening of the transcondylar distance The fibular head lies almost at the level of the tibial plateau and clinically there was evidence of peroneal palsy

CHAPTER 21

Fractures of the Leg

Fractures of the leg may involve either one or both of its constituent bones Although isolated fractures of the fibula occur, fractures of this bone are more commonly seen in association with fractures of the tibia Because of its weight-bearing function it is the fracture of the tibia that is of prime importance in fractures of the leg Fractures of the tibia may occur at the upper end, the so-called tibial plateau, where they involve the knee joint, in the shaft or at the lower end where they involve the mortise of the ankle joint

FRACTURES OF THE UPPER END OF THE TIBIA

Fractures of the upper end of the tibia involve either one or both of the tibial condyles, the tibial spines, or the tibial tubercle Fractures of the tibial plateau are usually considered as a unit though they may be more properly subdivided into those that involve the entire plateau (bicondylar fractures) and those that involve one or the other of the condyles (medial or lateral condylar fractures) The bicondylar fractures are usually due to direct violence and, owing to their frequent occurrence after automobile injuries, have been called bumper fractures The unilateral condylar fractures usually result from indirect violence following a fall landing on the feet and are frequently associated with injury to the collateral ligaments of the knee joint

Bicondylar Fractures

Bicondylar fractures are frequently comminuted and may be characterized by displacement or widening of the knee joint Since they invariably involve the articular surface of the upper end of the tibia they are associated with a marked hemarthrosis which must be aspirated repeatedly if necessary If the anatomical configuration of the tibial plateau is relatively well maintained simple immobilization in a plaster of Paris cast extending from the mid thigh down to and including

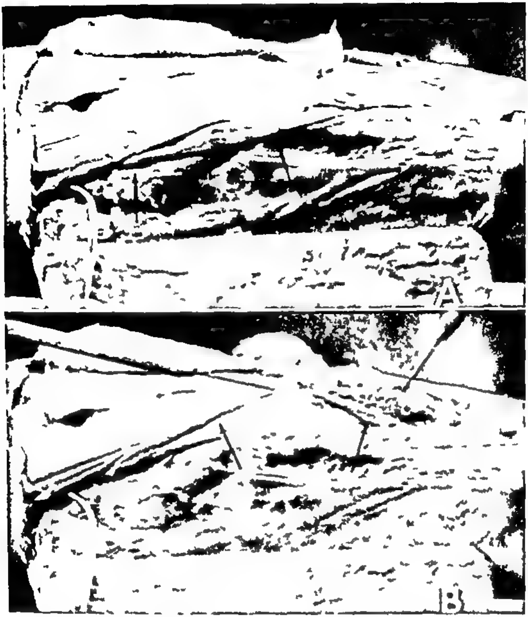


Fig 402 Anterior transplantation of the peroneal nerve (*A*) Normal position of the peroneal nerve is indicated by the arrows (*B*) After releasing the tibial head of the peroneus longus muscle the peroneal nerve may be easily transplanted from its posterolateral position to an anterior position in front of the superior tibiofibular articulation The nerve remains in the transplanted position following resuture of the tibial head of the peroneus longus tendon (Reproduced from Milch H Anterior transposition of the peroneal nerve for traction paralysis *J Bone & Joint Surg* 27 608 1945)

the ankle, with the knee in slight flexion, for a period of from four to eight weeks is sufficient (Fig 399) Quadriceps exercises should be instituted even while the leg is immobilized in the cast When there is evidence of adequate union, the cast may be removed and active motion may be gradually instituted within four to six weeks after removal of the cast

Where there is a moderate broadening of the upper end of the tibia as the result of impaction of the upper end of the tibial shaft between the fragments, skeletal traction should be applied through the lower end of the tibia to withdraw the upper end from between the fractured fragments (Fig 47) The fragments may then be forcibly compressed, using an ordinary carpenter s clamp This should,

FIG 401 Peroneal palsy following bumper fracture Traction was unavailing for reduction of the fracture and the patient developed a peroneal palsy This was corrected by resection of the fibular head with prompt subsidence of the paralytic symptoms

however, be applied quickly and for only a short period of time so as to avoid pressure necrosis of the skin

Occasionally as a result of increasing the transverse diameter of the upper end of the tibia, the fibula is pushed laterally and the peroneal nerve, as it crosses the neck of the fibula is put under tension with a resulting dropped foot (Fig 400)

Paralysis of the peroneal nerve may occur as a result of stretching This must be recognized promptly and its treatment takes precedence over the treatment of the fracture Traction paralysis of the peroneal nerve may be corrected by removing the upper end of the fibula (Fig 401) so as to shorten the distance the nerve must traverse, and thus to reduce tension on the nerve It may similarly be treated by anterior transplantation of the peroneal nerve from its normal posterolateral to an anterior position (Fig 402)

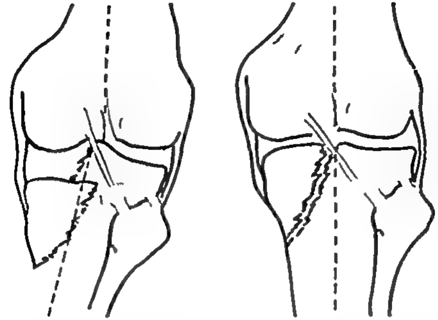


FIG 404 Fracture of the medial tibial condyle There is downward depression of the medial condyle (*left*) Because of the attachment of the tibial collateral ligament abduction of the leg (distal fragment) causes tension to be applied to the tibial collateral ligament and the small fragment is held fixed while the main shaft is realigned (*right*)

FIG 405 Posttraumatic genu varum Following an inadequately reduced depressed fracture of the medial condyle a genu varum deformity has developed This caused the patient no difficulty and no further treatment was indicated

Unicondylar Fractures

Isolated fractures of either the medial or lateral condyle may occur as a result of falls or blows where the force is directed obliquely against the leg The key to success in the treatment of these fractures depends upon the arrangements of the collateral ligaments of the knee joint The tibial collateral ligament is inserted directly into the medial condyle of the tibia and may be used as a counterforce in realigning fractures of the medial tibial condyle The fibular collateral ligament on

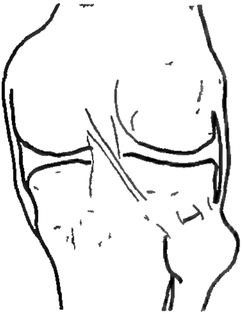


Fig 403 The integrity of the knee joint is maintained by its collateral ligament The tibial collateral ligament is inserted into the medial condyle of the tibia The fibular collateral ligament is inserted into the tip of the fibula

the other hand is inserted into the head of the fibula and does not permit of exertion of a counterforce in realigning fractures of the lateral tibial condyle (Fig 403)

Fractures of the Medial Condyle

Fractures of the medial condyle of the tibia appear to be considerably less common than those of the lateral condyle If seen early after injury these fractures can usually be reduced by abducting the leg against the counterforce exerted by the powerful tibial (medial) collateral ligament (Fig 404) If satisfactory position is attained, the leg should be immobilized in slight flexion for a period of about eight weeks in a long leg cast After removal of the cast, active motion without weight bearing may be begun and the patient may be ambulant on crutches After an additional four- to six-week period gradually increasing weight bearing may be permitted

Where there is marked depression of the medial condyle that cannot be overcome by abduction of the leg open operation and bolting of the fragments must be performed, provided there is a sufficiently firm cortex on the medial aspect of the condyle to support a bolt If the cortex is not judged to be sufficiently firm the fracture should be immobilized in a cast until firm union has occurred A varus of

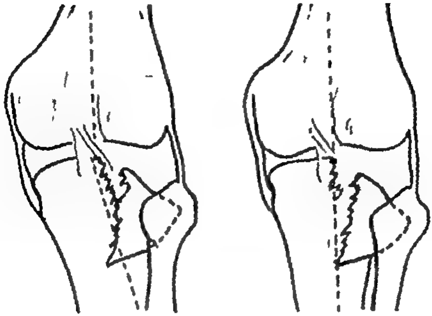


FIG 407 Depressed fracture of the lateral tibial condyle The lateral condyle is fractured and depressed (*left*) Because of the fact that the fibular collateral ligament is inserted into the tip of the fibula adduction of the leg (distal fragment) tenses the fibular collateral ligament to its maximum without exerting any effect on the depressed lateral condyle (*right*)

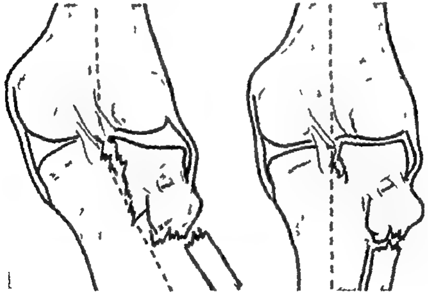


FIG 408 Depressed fracture of the lateral tibial condyle associated with fracture of the neck of the fibula There is a depressed fracture of the lateral condyle with a fracture of the fibular neck (*left*) If the superior tibiofibular ligaments are intact adduction of the leg will serve to tense the fibular collateral ligament and thus reduce the depressed fractured tibial condyle with the fractured fibular neck (*right*)

the leg will develop in consequence of the uncorrected malalignment No further treatment is indicated if the deformity is of moderate degree (Fig 405) On the other hand, a marked degree of varus can be readily corrected by the performance of a simple lineal osteotomy (Fig 406)

FIG 406 Posttraumatic genu varum Following an inadequately reduced medial condylar fracture a marked bowleg developed (*left*) *This was corrected by simple lineal osteotomy (right)* (Reproduced from Milch H Juxta articular partial tibial osteotomy *Surg Gynec & Obst 59* 87 1934)

FRACTURES OF THE LATERAL CONDYLE

Fracture of the lateral condyle of the tibia presents an entirely different problem from that of the medial condyle There is not infrequently an associated injury to the tibial collateral ligament, the most important ligamentous structure about the knee Because of the fact that the fibular collateral ligament is inserted into the head of the fibula and not into the tibial condyle, it is usually impossible to replace the depressed condylar fragment by adduction of the leg since no counterforce can be exerted directly on the lateral condyle (Fig 407) On the other hand, where the fibular neck is fractured at the same time as is the lateral condyle and the restraining influence of the fibular collateral ligament is removed, adduction of the limb the opposite maneuver to that used in fractures of the medial condyle will frequently permit molding and satisfactory reduction of the fracture (Figs 408

FIG 410 Fracture of the lateral tibial condyle Depressed fracture of the lateral condyle (*left*) was treated by open operation and bolt fixation of the fragment (*right*) (Courtesy of Dr H Sternberg)

FIG 411 Depressed fracture of the lateral tibial condyle There has been only slight depression of the fragment without any marked disturbance of the level of the articular plateau (*left*) The patient was treated by simple cast immobilization with only slight increase in genu valgum and no disturbance in joint function (*right*)

and 409) In such event, the leg should be immobilized in a long leg cast in a position of slight flexion for a period of six to eight weeks Thereafter, progressively increasing weight bearing may be permitted As in all fractures about the knee, meticulous attention should be directed toward maintaining the tone of the quadriceps femoris group of muscles by quadriceps exercises, which should be performed within the cast

Ideally, perfect anatomical reposition of the fragments is to be desired, since this fracture is intraarticular and may lead to a posttraumatic arthritis Such ideal

Fig 409 Fracture of the fibular neck and the lateral tibial condyle The superior tibiofibular ligaments have not been injured and the fractured fibula and the lateral condyle act as a single fragment Adduction of the leg against the counterforce exerted by the fibular collateral ligament served to realign the fragments

reposition can be obtained only by open operative intervention and bolting of the fragment (Fig 410) This can be accomplished only provided there is a sufficiently firm cortex in the lateral fragment to permit passage and solid fixation of the bolt The defect that results from elevation of the depressed condylar fragment should be filled by cancellous bone grafts

Where a rupture of the tibial collateral ligament is suspected or can be demonstrated the limb should be immobilized in a plaster of Paris long leg cast for at least six weeks to permit adequate healing of the ligament If after removal of the cast, hyperabductability of more than five degrees persists repair of the tibial collateral ligament may be necessary Where no injury to the tibial collateral ligament

Fig 410 Fracture of the lateral tibial condyle Depressed fracture of the lateral condyle (*left*) was treated by open operation and bolt fixation of the fragment (*right*) (Courtesy of Dr H Sternberg)

Fig 411 Depressed fracture of the lateral tibial condyle There has been only slight depression of the fragment without any marked disturbance of the level of the articular plateau (*left*) The patient was treated by simple cast immobilization with only slight increase in genu valgum and no disturbance in joint function (*right*)

FIG 412 Traumatic genu valgum in an adolescent Synchondrosis of the lateral half of the epiphysis occurred with progressive genu valgum (*left*) Correction by various types of tibial and femoral osteotomy was unsuccessful until after the fibular collateral ligament was detached and a juxta articular tibial osteotomy was performed (*right*) (Reproduced from Milch H Juxta articular partial tibial osteotomy *Surg Gynec & Obst 59* 87 1934)

FIG 413 Marginal fracture of the anterior lip of the tibia Accidental finding in a patient who presented no symptoms of a fracture sustained during childhood No treatment was indicated

can be demonstrated after bolting the leg may simply be supported in balanced suspension and passive motion may be instituted immediately by means of a Pearson attachment Active motion is begun as soon as possible thereafter Weight bearing however, should be avoided for a period of at least three months, and should then only gradually be resumed

Fig 414 Marginal fracture of the lateral tibial condyle There is a transverse fracture of the lateral tibial condyle without displacement No treatment was indicated other than for control of pain

Fig 415 Segond s fracture of the lateral tibial condyle The fracture line is usually vertical and represents an avulsion of a small fragment of cortical bone from the site of insertion of the tensor fasciae femoris tendon Simple immobilization is indicated primarily for control of pain

Not every fracture of the lateral condyle however, demands open operation and even depressed fractures treated conservatively may result in a perfectly normally functioning knee joint (Fig 411)

Where fracture of the lateral condyle occurs during adolescence, synchondrosis of the lateral half of the epiphyseal line with resulting marked genu valgum may ensue This can be corrected by osteotomy at the upper end of the tiba but only after the fibular collateral ligament has been detached from the head of the fibula and reattached to the elevated portion of the tibial condyle (Fig 412)

FIG 412 Traumatic genu valgum in an adolescent Synchondrosis of the lateral half of the epiphysis occurred with progressive genu valgum (*left*) Correction by various types of tibial and femoral osteotomy was unsuccessful until after the fibular collateral ligament was detached and a juxta articular tibial osteotomy was performed (*right*) (Reproduced from Milch H Juxta articular partial tibial osteotomy *Surg Gynec & Obst 59* 87 1934)

FIG 413 Marginal fracture of the anterior lip of the tibia Accidental finding in a patient who presented no symptoms of a fracture sustained during childhood No treatment was indicated

can be demonstrated after bolting, the leg may simply be supported in balanced suspension and passive motion may be instituted immediately by means of a Pearson attachment Active motion is begun as soon as possible thereafter Weight bearing, however, should be avoided for a period of at least three months, and should then only gradually be resumed

FIG 414 Marginal fracture of the lateral tibial condyle There is a transverse fracture of the lateral tibial condyle without displacement No treatment was indicated other than for control of pain

FIG 415 Segond s fracture of the lateral tibial condyle The fracture line is usually vertical and represents an avulsion of a small fragment of cortical bone from the site of insertion of the tensor fasciae femoris tendon Simple immobilization is indicated primarily for control of pain

Not every fracture of the lateral condyle, however, demands open operation and even depressed fractures treated conservatively may result in a perfectly normally functioning knee joint (Fig 411)

Where fracture of the lateral condyle occurs during adolescence, synchondrosis of the lateral half of the epiphyseal line with resulting marked genu valgum may ensue This can be corrected by osteotomy at the upper end of the tiba but only after the fibular collateral ligament has been detached from the head of the fibula and reattached to the elevated portion of the tibial condyle (Fig 412)

FIG 416 Segond s fracture of the lateral tibial condyle There is a small avulsion fracture of the cortex of the lateral condyle Union has not occurred but no treatment is indicated This type of fracture must be carefully differentiated from avulsion of the head of the fibula (See Fig 436)

FIG 417 Recurvatum deformity of the knee Downward and forward sloping of the superior articular surface of the tibia (*left*) has been corrected by simple angulational osteotomy (*right*) (Reproduced from Milch H Juxta articular partial osteotomy *Surg Gynec & Obst* 59 87 1934)

Marginal fractures of either the anterior lip (Fig 413) or the lateral condyle (Fig 414) usually require no treatment other than simple immobilization until the period of pain has passed

An unusual fracture of the lateral condyle (*Segond's fracture*) may result from avulsion by the tendon of insertion of the tensor fasciae femoris (Figs 415 and 416) This fracture must be carefully differentiated from avulsion fractures of the tip of the fibula at the insertion of the fibular collateral ligament or the biceps femoris muscle (Fig 436)

Recurvatum deformity of the knee owing to downward and forward sloping of the upper end of the tibia may result from a compression fracture This can be corrected by an oblique osteotomy (Fig 417)

Fractures of the Tibial Spines

Fractures of the tibial spines may occur at any age and may involve either the medial or the lateral spine These injuries may be associated with fracture of one or the other of the condyles or may occur as isolated injuries Fracture of the medial tibial spine has been attributed to avulsion by the anterior cruciate ligament, while fracture of the lateral spine has been described as being caused by blows directed against the flexed knee with backward propulsion of the femur on the fixed tibia When there is but little displacement (Fig 418) the knee should be immobilized in a plaster of Paris cast with the leg fully extended for a period of four to five weeks Quadriceps exercises should be instituted from the very outset of the condi-

FIG 418 Fracture of the tibial spine There is essentially no displacement of the fragment and treatment should consist of simple cast immobilization with the knee in extension

tion so as to maintain the tone of this muscle After the cast is removed, active motion may be instituted and weight bearing with the aid of crutches may be started

If there is displacement of the fragment, extension of the knee may be limited An effort should be made to overcome the displacement by manipulation If this is unsuccessful and the bone block persists, open operation is indicated Although occasional good results may be obtained by replacing and fixing the tibial spine, the likelihood of postoperative limitation of motion should not be overlooked It has been repeatedly demonstrated that, *provided the tibial collateral ligament is intact* the tibial spine and either one or both of the cruciate ligaments may be excised without jeopardizing the function of the knee joint It would appear to be preferable

Fig 419 Fracture of the tibial spine There is marked displacement of the fractured fragment with limitation of extension of the knee joint The fragment should be excised in preference to attempts at reduction

therapy to excise the fragment and to institute early motion rather than to attempt preservation of the fragment with the risk of limitation of motion (Fig 419)

Fractures of the Tibial Tubercle

In the adult fractures of the tibial tubercle usually result from avulsion by force exerted through the patellar tendon (Fig 420) There is immediate loss of the power of extension and the only treatment is by open operation To insure against detachment by the patellar tendon during the period of healing, the fragment of bone should be firmly fixed to the head of the tibia by a screw or ivory peg (Fig 421)

In children, *avulsion of the tibial tubercle* has been misnamed Osgood Schlatter's disease There is no valid evidence to justify its designation as a disease entity and its mode of origin, as well as its response to treatment would tend rather to establish the condition as of traumatic origin The condition invariably occurs in children before the age of eighteen years at which time the tibial apophysis unites with the head of the tibia The onset is usually associated with excessive strain on the patellar tendon and the condition is characterized by swelling localized tenderness, and pain on extension of the knee against resistance

FIG 420 Fracture of the tibial tubercle Avulsion of the tibial tubercle with upward displacement of the fragment has resulted from the pull of the patellar tendon

FIG 421 Fracture of the tibial tubercle The avulsed portion of the tibial tubercle has been pulled down and held in place by an ivory peg

Where there is merely elevation or even fragmentation of the tibial apophysis (Fig 422), simple immobilization in a long leg plaster of Paris cast with the knee in extension for six to eight weeks usually suffices to bring about subsidence of the symptoms On removal of the cast, the child should be cautioned against resumption of strenuous activity, since symptoms may recur at any time prior to bony closure of the apophysis Drilling or screw fixation of the apophysis is to be avoided as unnecessary, particularly in young girls where the ultimate result may be an un-

Fig 422 Fracture of the apophysis of the tibial tubercle so called Osgood Schlatter disease The lingula has been elevated on both sides and shows discontinuity suggestive of fracture Simple immobilization with the knee in extension usually suffices to control the symptoms

sightly prominence in the region of the tibial tubercle Where there is complete avulsion of the apophysis, surgical intervention and fixation of the avulsed tubercle is unavoidable

FRACTURES OF THE TIBIAL SHAFT

Isolated fracture of the tibial shaft is not uncommon It may follow direct or indirect trauma and, because the intact fibula acts as an internal splint, there is frequently but little separation of the fragments Immobilization may be accomplished

by a skintight or a lightly padded plaster of Paris cast extending from above the knee to and including the foot, with the knee in slight flexion. The cast is maintained in position for a period of eight to twelve weeks, or until healing is complete. After removal of the cast, weight bearing may be permitted with a two bar leg brace for an additional period of three months.

Because of the danger of torsion in short spiral fractures, even within the cast, transfixion of the fracture by Kirschner wires that are incorporated in the cast is a

FIG 423 *Spiral fractures of the tibial shaft.* There is a slight torsional displacement which has been controlled by Kirschner wires transfixing both the proximal and distal fragments. The wires are incorporated in the cast which extends from the toes to the mid thigh.

desirable precaution (Fig 423). Traction should be used with great caution in such instances. Healing is notoriously slow, especially in fractures of the lower third of the tibia, and traction seems to act to prolong the period of ultimate healing. Delayed union and nonunion are not uncommon sequelae of tibial shaft fractures and, where these are feared, bone plating or screw fixation at right angles to the line of fracture should be undertaken.

An alternative procedure is by means of intramedullary fixation for which the Lottes nail is particularly well adapted. It is, however, best suited for fractures that occur within an area three inches proximal to the ankle joint and three inches distal to the tibial tubercle (Fig 424*A* and *B*). The nail is inserted through a cortical window drilled at the level of the mid-portion of the tibial tubercle and directed down

ward toward the course of the medullary canal The width of the nail is determined by the diameter of the narrowest portion of the medullary canal, which occurs at the junction of the middle and lower thirds of the tibial shaft On the average, this diameter is about 0 37 inches (0 93 cm), but there are individual variations that should be determined on x rays of this area After nailing, a long leg cast is applied

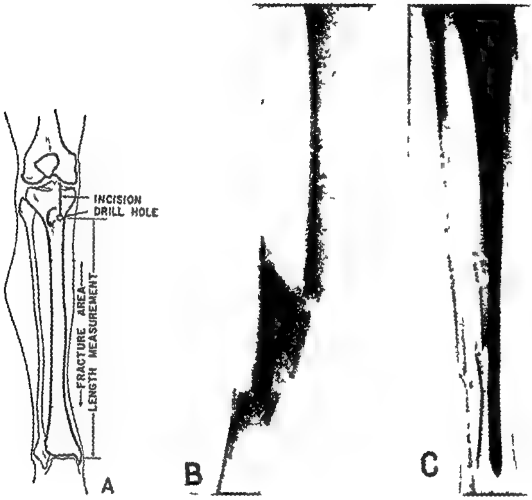


Fig 424 Insertion of Lottes nail (*A*) The area within which the nail may be employed for tibial fractures is indicated in relation to the length of the nail to be used and the site of its insertion (Reproduced from Lottes J O Blind nailing technique for introduction of tri flanged medullary nail *J A M A* *155* 1039 1954) Comminuted fracture of tibia and fibia (*B*) treated by intermedullary nailing of tibia (*C*)

and the patient may be permitted to be ambulant after about two weeks Walking without a cast may be permitted after about three months, when there should be evidence of satisfactory healing If not weight bearing should be interdicted until there is roentgen evidence of adequate healing When healing is complete, the nail may be removed or left permanently in situ

Where there is definite displacement accurate axial alignment must be obtained It is an error to believe that an angulational displacement will be corrected by sub

sequent remodeling, even in children (Fig 425) Skeletal traction by a pin through the distal fragment with countertraction exerted against the femur with the knee in ninety degrees of flexion, affords an efficient means of restoring axial alignment A plaster of Paris cast incorporating the transfixion pin should be applied with the knee in slight flexion A second pin, inserted through the proximal fragment and incorporated in the cast, makes the fixation more secure

FIG 425 Malaligned tibial fracture in a child Persistent bowing of the tibia with medial convergence of the tibial articulations will persist despite remodeling at the site of fracture Osteotomy is necessary to correct this bowing

This method of treatment is usually not applicable to instances in which there are multiple fractures of the tibia It is particularly in such cases that intramedullary nailing has been advocated (Fig 424*B*) Equally satisfactory results may be obtained however, by the use of a long metallic plate The plate should be fixed and held to the most proximal fragment by means of a bone holding forceps while the next most distal fragment is brought into alignment and both are firmly fixed to the

ward toward the course of the medullary canal The width of the nail is determined by the diameter of the narrowest portion of the medullary canal, which occurs at the junction of the middle and lower thirds of the tibial shaft On the average, this diameter is about 0 37 inches (0 93 cm), but there are individual variations that should be determined on x-rays of this area After nailing a long leg cast is applied

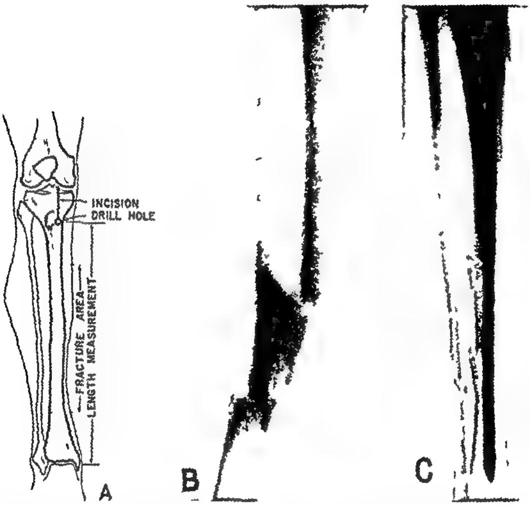


FIG 424 Insertion of Lottes nail (*A*) The area within which the nail may be employed for tibial fractures is indicated in relation to the length of the nail to be used and the site of its insertion (Reproduced from Lottes J O Blind nailing technique for introduction of tri flanged medullary nail *J A M A 155* 1039 1954) Comminuted fracture of tibia and fibia (*B*) treated by intermedullary nailing of tibia (*C*)

and the patient may be permitted to be ambulant after about two weeks Walking without a cast may be permitted after about three months, when there should be evidence of satisfactory healing If not, weight bearing should be interdicted until there is roentgen evidence of adequate healing When healing is complete, the nail may be removed or left permanently in situ

Where there is definite displacement accurate axial alignment must be obtained It is an error to believe that an angulational displacement will be corrected by sub-

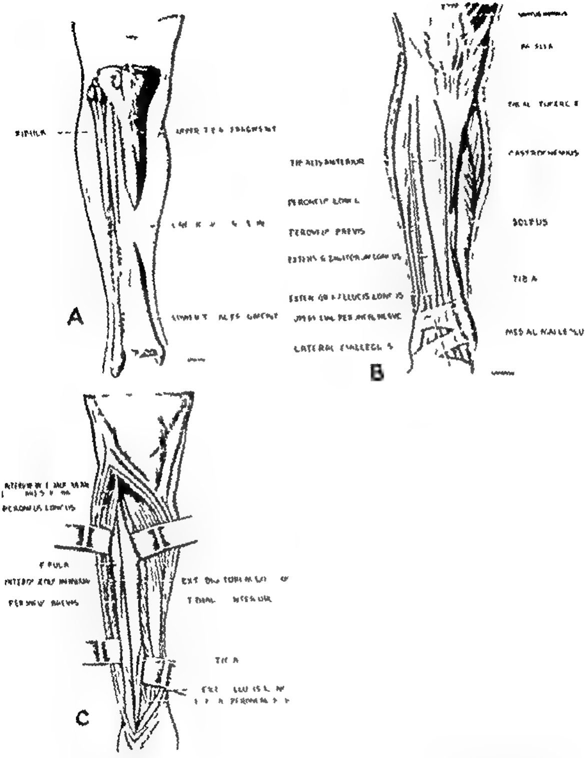


Fig 428 Synostosis operation for persistent nonunion of the tibia (*A*) The skin incision is made over the anterior compartment of the leg The edges are retracted exposing the deep fascia (The broken lines indicate the lines of osteotomy of the bones later to be carried out) (*B*) The deep fascia is incised longitudinally along the course of the superficial branch of the peroneal nerve and the peroneal muscles are retracted laterally exposing the fibula and the outer half of the interosseous membrane (C) The fascia incised along the crest of the tibia and the attached muscles are separated (Reproduced from Milch H Tibio fibular synostosis *Surgery* 27 770 1950)

FIG 426 Multiple fractures of the leg Adequate alignment was not obtained by transfixion wires and immobilization in a plaster cast

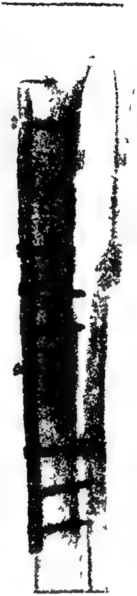


FIG 427 Plate fixation of multiple tibial fractures Same case as Fig 426 after realignment of fragments and fixation by means of a metallic plate

plate by adequate screws The uppermost forceps may then be removed and used for the purpose of realigning the next most distal fragment which is then similarly fixed to the plate This is continued working distally until all the major fragments have been aligned (Figs 426 and 427) The limb is then immobilized in a long leg cast and treated in the same manner as all other fractures of the tibial shaft

Persistent nonunion of tibial shaft fractures owing to loss of subsistence in the diaphysis, presents a particularly difficult problem It has been treated by onlay bone grafting and by transplantation of the fibula into the tibia When successful

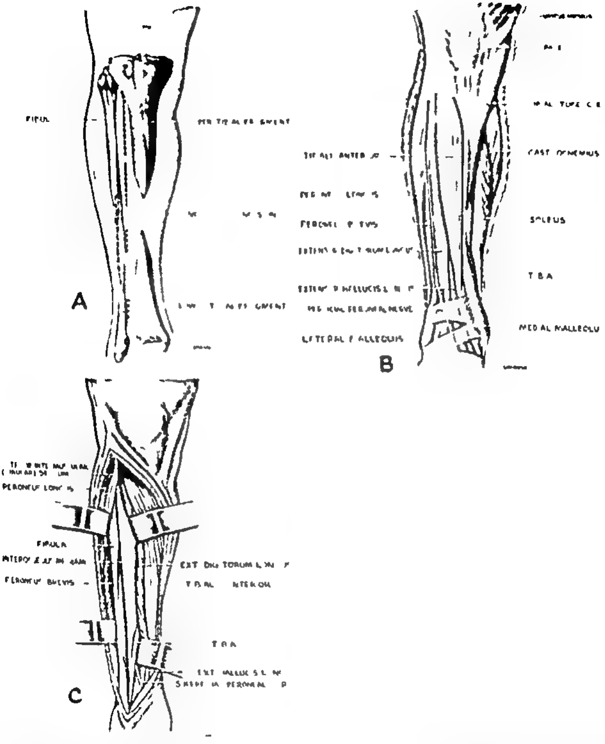


FIG 428 Synostosis operation for persistent nonunion of the tibia (*A*) The skin incision is made over the anterior compartment of the leg The edges are retracted exposing the deep fascia (The broken lines indicate the lines of osteotomy of the bones later to be carried out) (*B*) The deep fascia is incised longitudinally along the course of the superficial branch of the peroneal nerve and the peroneal muscles are retracted laterally exposing the fibula and the outer half of the interosseous membrane (*C*) The fascia incised along the crest of the tibia and the attached muscles are separated (Reproduced from Milch H Tibio fibular synostosis *Surgery* *27* 770 1950)

FIG 426 Multiple fractures of the leg Adequate alignment was not obtained by transfixion wires and immobilization in a plaster cast

FIG 427 Plate fixation of multiple tibial fractures Same case as Fig 426 after realignment of fragments and fixation by means of a metallic plate

plate by adequate screws The uppermost forceps may then be removed and used for the purpose of realigning the next most distal fragment which is then similarly fixed to the plate This is continued working distally until all the major fragments have been aligned (Figs 426 and 427) The limb is then immobilized in a long leg cast and treated in the same manner as all other fractures of the tibial shaft

Persistent nonunion of tibial shaft fractures owing to loss of subsistence in the diaphysis, presents a particularly difficult problem It has been treated by onlay bone grafting and by transplantation of the fibula into the tibia When successful,

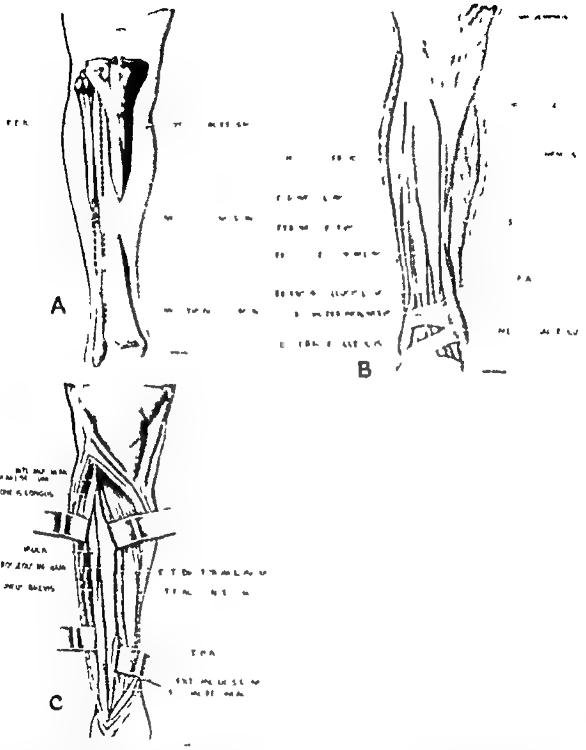


FIG 428 Synostosis operation for persistent nonunion of the tibia (*A*) The skin incision is made over the anterior compartment of the leg The edges are retracted exposing the deep fascia (The broken lines indicate the lines of osteotomy of the bones later to be carried out) (*B*) The deep fascia is incised longitudinally along the course of the superficial branch of the peroneal nerve and the peroneal muscles are retracted laterally exposing the fibula and the outer half of the interosseous membrane (C) The fascia incised along the crest of the tibia and the attached muscles are separated (Reproduced from Milch H Tibio fibular synostosis *Surgery* 27 770 1950)

these procedures afford excellent stability and the fibula usually increases in diameter under the stress of weight bearing The latter operation, however, has the disadvantage that if it fails, the leg becomes incapable of supporting weight and permanent use of a brace, or even amputation, may have to be contemplated A less dangerous and usually efficacious alternative is afforded by creating a synostosis between the inner portion of the fibula and each of the tibial fragments (Figs 428 and 429)

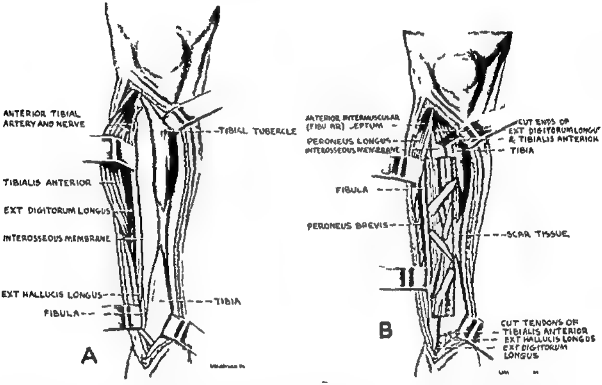


Fig 429 (*A*) The muscle mass of the anterior compartment including the anterior tibial vessels and nerves is elevated exposing the medial portion of the fibula the interosseous membrane and the lateral portion of the tibia (*B*) The tibial fragments are split longitudinally and the lateral halves are turned outward against the interosseous membrane The fibula is split longitudinally and its medial half is laid down along the interosseous membrane inosculating with the tibial fragments previously laid down

The skin incision is made between the fibula and the tibia over the muscle mass lying in the anterior compartment of the leg (Fig 428*A*) The skin edges are retracted and the emergence of the superficial branch of the peroneal nerve from beneath the fascia is sought Following this nerve the deep fascia along the outer aspect of the anterior group of muscles is incised Another incision is made along the crest of the tibia on the inner aspect of the anterior group of muscles (Fig 428*B*) The peroneal muscles are retracted outward (*Fig 428C*) The whole muscle mass, including the anterior tibial vessels and nerves, is elevated and retracted exposing the inner side of the fibula, the interosseous membrane, the outer side of

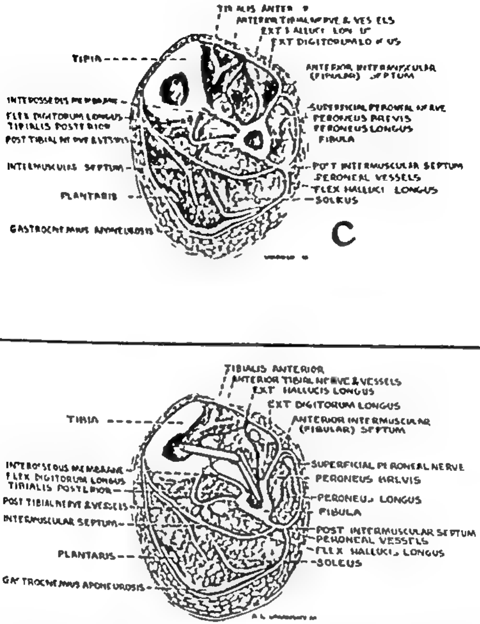


Fig 429 (*Contd*) (*C*) Cross section of the leg before (*above*) and after the synostosis operation (*below*) showing the relation of the synostosing bone fragments to the tibia the fibula and the interosseous membrane (Reproduced from Milch H, Tibio fibular synostosis *Surgery* 27 770 1950)

the tibia and the intervening site of nonunion of the tibia (Fig 429*A*) The outer half of each of the tibial fragments is split longitudinally along the crest and the fragments are turned outward and laid down against the interosseous membrane The fibula is split longitudinally throughout its whole length and its inner half is laid down against the interosseous membrane where it interlocks with the tibial fragments (Fig 429*B*) The muscle mass is permitted to fall back above the bone fragments and the fascia is closed with interrupted chromic sutures The skin is closed without drainage and a plaster of Paris cylinder is applied until there is x-ray

these procedures afford excellent stability and the fibula usually increases in diameter under the stress of weight bearing The latter operation, however, has the disadvantage that if it fails, the leg becomes incapable of supporting weight and permanent use of a brace, or even amputation, may have to be contemplated A less dangerous and usually efficacious alternative is afforded by creating a synostosis between the inner portion of the fibula and each of the tibial fragments (Figs 428 and 429)

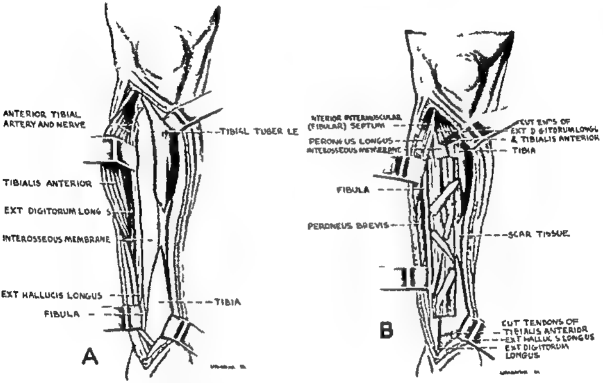


Fig 429 (*A*) The muscle mass of the anterior compartment including the anterior tibial vessels and nerves is elevated exposing the medial portion of the fibula the interosseous membrane and the lateral portion of the tibia (*B*) The tibial fragments are split longitudinally and the lateral halves are turned outward against the interosseous membrane The fibula is split longitudinally and its medial half is laid down along the interosseous membrane inosculating with the tibial fragments previously laid down

The skin incision is made between the fibula and the tibia over the muscle mass lying in the anterior compartment of the leg (Fig 428*A*) The skin edges are retracted and the emergence of the superficial branch of the peroneal nerve from beneath the fascia is sought Following this nerve the deep fascia along the outer aspect of the anterior group of muscles is incised Another incision is made along the crest of the tibia on the inner aspect of the anterior group of muscles (Fig 428*B*) The peroneal muscles are retracted outward (Fig 428*C*) The whole muscle mass, including the anterior tibial vessels and nerves, is elevated and retracted exposing the inner side of the fibula the interosseous membrane the outer side of

in nature and involve the ankle joint In children, separation of the lower tibial epiphysis may occur

SUPRAMALLEOLAR FRACTURES

The supramalleolar fracture may involve only the tibia or both the tibia and the fibula In the latter instance, the fracture of the fibula occurs at a higher level

FIG 431 Torus type of supramalleolar fracture of the tibia The alignment is satisfactory and treatment by simple cast immobilization suffices

FIG 432 Comminuted supramalleolar fracture of the tibia and fibula Internal torsion is present and was maintained by interposition of the peroneal tendons between the fibular fragments This could be corrected only by operative intervention and release of the peroneal tendons

than that of the tibia No fracture of the lower end of the tibia should be considered as properly investigated unless the roentgenogram includes the whole of the fibula Where the fracture is of the torus type (Fig 431), simple immobilization in a short leg plaster cast reaching to below the knee affords adequate treatment This should be maintained until there is evidence of union, usually six to eight weeks Weight bearing should be prohibited until this time

If the fracture is comminuted reduction and alignment of the fragments may be obtained by skeletal traction exerted by a pin driven through the os calcis (Fig

Fig 430 Synostosis operation for persistent nonunion of the tibia (*left*) Following synostosis operation union has occurred between the osteotomized fibula and the separate portions of the tibia (*right*) (Reproduced from Milch H Tibio fibular synostosis *Surgery 27* 770 1950)

evidence of bone healing along the area of synostosis To prevent bowing of the tibia, a two-bar brace should be worn until bone healing is solid (Fig 430)

FRACTURES OF THE LOWER END OF THE TIBIA

Fractures at the lower end of the tibia in adults may occur at a level above the malleoli, the so called supramalleolar fracture of Malgaigne, or may be longitudinal

FIG 434 Synchondrosis of the lower tibial epiphysis The original injury consisted of an epiphyseal separation of the lower end of the fibula and a longitudinal fracture of the medial malleolus extending through the epiphyseal plate Synchondrosis occurred in this area but not in the region of the epiphyseal separation of the fibula As a consequence a marked varus at the ankle with a varus deformity of the foot developed

FIG 435 Synchondrosis of the lower tibial epiphysis Angulational osteotomy of the lower end of the tibia of patient shown in Fig 434 has been performed to restore the axial alignment of the ankle joint mortise (See Fig 456)

47) Occasionally, reduction is impossible either by manipulation or by skeletal traction In such event, the possibility of interposition of the peroneal tendons between the fibular fragments must be envisioned and open operation must be performed to release these tendons (Fig 432) Accurate reposition of the fragments by rotation usually suffices to maintain alignment The foot and leg may then be immobilized in a skintight or lightly padded plaster cylinder extending to above the slightly flexed knee

Separation of the Lower Tibial Epiphysis

Separation of the lower tibial epiphysis is more common than that of the upper epiphysis The epiphyseal fragment is usually displaced posteriorly and

Fig 433 Separation of the lower tibial epiphysis The distal fragment is displaced posteriorly to a minimal degree No treatment other than cast immobilization is necessary

laterally and may be associated with a triangular fracture fragment from the outer portion of the lower end of the tibia Where the displacement is minimal, no treatment is usually required except for simple immobilization in a short leg cast to control pain (Fig 433) Where on the other hand, marked displacement has occurred, manipulative reduction of the separation is usually possible in early cases Open reduction may be necessary if the injury is first seen after several weeks

This type of epiphyseal injury usually does not result in any impairment of growth since there is no compression of the epiphyseal plate in most instances On the other hand, where longitudinal compression of the epiphyseal plate occurs synchondrosis may result with the subsequent development of a marked varus at the ankle (Fig 434) Such consequences should be treated by osteotomy to re-

fibula, since it almost always heals and causes but little disability even when healed in malposition

Isolated fractures of the fibula are, therefore, more important in their recognition for the control of pain than for the correction of a malalignment

At its upper end, *fractures of the styloid process* of the fibula may vary from small fragments to large portions of the head of the bone (Figs 436 and 437) Most frequently, they result from avulsion either by the attached collateral ligament or the tendon of the biceps femoris muscle The smaller fragment should be differentiated from the *Segond fracture* (Fig 416) resulting from avulsion of

FIG 437 Avulsion fracture of the upper end of the fibula The entire upper end of the fibula has been displaced directly upward Where the fragment acts to block knee joint function it may either be excised or resutured into its normal position Where it is excised it is important to reattach the fibular collateral ligament and the biceps femoris tendon

the cortex of the lateral tibial condyle by the tendon of the tensor fasciae femoris Neither of these types requires any special treatment other than temporary immobilization to control pain unless the fragment is displaced upward toward the level of the knee joint where it may act as a bone block In this event, the fragment may either be replaced and sutured or may be excised with reattachment of the fibular collateral ligament and the biceps femoris tendon

Traction injuries to the peroneal nerve may occasionally occur with this type of fracture, but it is more common in fractures that involve the neck of the fibula Fractures in this region associated with evidence of peroneal palsy, should be treated by open operation If the continuity of the nerve has not been interrupted, anterior transplantation of the nerve or resection of the fibular head may lead to subsidence of the paralytic symptoms If the nerve is actually lacerated an effort at primary repair should be made

store the normal relationship of the ankle joint mortise to the shaft of the tibia (Fig 435) Depending upon the age at which the deformity occurs, repeated osteotomy may be necessary until all growth has ceased in the fibula and in the lateral portion of the lower tibial epiphysis

This is to be preferred to epiphysiodesis, or destruction of the uninvolved outer portion of the tibial epiphysis Such a procedure leads to an overgrowth of the fibula with recurrent varus deformity of the leg unless the fibular epiphysis is simultaneously obliterated If both are obliterated, the result is a disparity in length between the two legs, which may later require surgical correction Repeated osteotomy avoids these contingencies

Longitudinal fractures of the lower end of the tibia are considered under fractures of the ankle joint

FRACTURES OF THE FIBULA

Fractures of the fibula are most commonly seen in association with fractures of the tibia In such instances but little attention is usually paid to the fractured

FIG 436 Avulsion fracture of the upper end of the fibula This fracture should be differentiated from Segond's fracture of the lateral tibial condyle though the treatment of both conditions is precisely the same (See Fig 416)

CHAPTER 22

Fractures about the Ankle Joint

Fractures about the ankle joint are almost innumerable in the variety of their appearance and many schemes for their diagnostic classification have been devised Ashhurst (1922) attempted a differentiation into first-, second-, and third-degree fractures based both upon their severity and the mechanism of their production While there is general concurrence as to the definition of first- and second degree fractures as unimalleolar and bimalleolar injuries, respectively, there is no unanimity of opinion as regards third-degree fractures, which have been variously defined by different authors

From a therapeutic and prognostic point of view, however, the only important differentiation is into those fractures that do not disrupt the mortise of the ankle joint and those that do Fractures that do *not* disrupt the mortise may involve one or both malleoli When one malleolus is involved the fracture line may occur anywhere along its extent When both malleoli are involved, however, the fracture lines *always* occur *below* the level of the superior surface of the astragalus Fractures that disrupt the mortise of the ankle joint may result either from a unimalleolar fracture with concomitant rupture of the collateral ligament attaching to the opposite malleolus or from a bimalleolar fracture In the latter event, the fracture line always occurs *at* or *above* the level of the superior articular surface of the astragalus (Fig 440)

In order to differentiate between those bimalleolar fractures that do not involve the ankle joint mortise and those unimalleolar fractures associated with ligamentous injuries that may lead to disruption of the mortise, it is extremely important to obtain not only the routine anteroposterior and lateral roentgenograms, but also oblique views, views with the foot in twenty five degrees of internal rotation (mortise view) as well as stress films with the foot in inversion or eversion

FRACTURES THAT DO NOT DISRUPT THE MORTISE

Fractures not disrupting the ankle joint mortise are of four general types (1) unimalleolar, external rotation fractures of the lateral malleolus, (2) unimalleolar,

FIG 438 Spiral fracture of the fibular shaft There is but little displacement and simple immobilization in a plaster boot until healing had occurred sufficed

FIG 439 Malunited fracture of the fibula Healing has occurred in external rotation but with no impairment in the function of the ankle joint

Fracture of the shaft of the fibula may be either comminuted, as the result of direct blows, or spiral, as the result of external rotation of the foot on the leg (Fig 438) Unless there is interposition of muscle, these fractures almost invariably heal Overriding is usually of no consequence Even external rotation of the distal fragment, which tends to rotate the mortise and, thus the foot externally, usually causes but little difficulty (Fig 439)

CHAPTER 22

Fractures about the Ankle Joint

Fractures about the ankle joint are almost innumerable in the variety of their appearance and many schemes for their diagnostic classification have been devised Ashhurst (1922) attempted a differentiation into first-, second-, and third-degree fractures based both upon their severity and the mechanism of their production While there is general concurrence as to the definition of first- and second-degree fractures as unimalleolar and bimalleolar injuries, respectively, there is no unanimity of opinion as regards third-degree fractures, which have been variously defined by different authors

From a therapeutic and prognostic point of view, however, the only important differentiation is into those fractures that do not disrupt the mortise of the ankle joint and those that do Fractures that do *not* disrupt the mortise may involve one or both malleoli When one malleolus is involved, the fracture line may occur anywhere along its extent When both malleoli are involved, however, the fracture lines *always* occur *below* the level of the superior surface of the astragalus Fractures that disrupt the mortise of the ankle joint may result either from a unimalleolar fracture with concomitant rupture of the collateral ligament attaching to the opposite malleolus or from a bimalleolar fracture In the latter event, the fracture line always occurs *at* or *above* the level of the superior articular surface of the astragalus (Fig 440)

In order to differentiate between those bimalleolar fractures that do not involve the ankle joint mortise and those unimalleolar fractures associated with ligamentous injuries that may lead to disruption of the mortise it is extremely important to obtain not only the routine anteroposterior and lateral roentgenograms, but also oblique views, views with the foot in twenty-five degrees of internal rotation (mortise view) as well as stress films with the foot in inversion or eversion

FRACTURES THAT DO NOT DISRUPT THE MORTISE

Fractures not disrupting the ankle joint mortise are of four general types (1) unimalleolar, external rotation fractures of the lateral malleolus, (2) unimalleolar,

FIG 440 Critical line for bimalleolar fractures Fractures at or below the level of the ankle joint usually do not result in disruption of the mortise Fractures above this line are almost invariably associated with disruptions of the ankle joint mortise

abduction or adduction fractures of either the medial or lateral malleoli, respectively (3) longitudinal fractures involving the anterior or posterior margins of the tibia or Tillaux tubercle, and (4) bimalleolar fractures occurring below the level of the superior articular surface of the astragalus

Malleolar Fractures

External rotation fractures of the lateral malleolus are characterized by a spiral fracture line, running upward and outward from at or above the level of the inferior tibiofibular joint (Fig 441) There is usually little if any displacement and reduction is accomplished by simply rotating the foot internally Immobilization in a walking plaster of Paris boot extending from the toes to just below the neck of the fibula with the foot in the neutral position for a period of three to four weeks, usually suffices to assure adequate healing Thereafter the ankle may be supported by adhesive tape strapping Where there is but little pain it is occasionally possible to immobilize these fractures by simple adhesive tape strapping from the very beginning

Unimalleolar abduction fractures are transverse fractures of the medial malleolus occurring at or below the level of the ankle joint (Fig 442) Nonunion or fibrous unions is not an uncommon complication of these fractures and reduction should be as accurate as possible to assure bone to bone contact This can

Fig 441 External rotation fracture of the lateral malleolus There is a spiral fracture of the lower end of the fibula at the level of the tibiofibular ligament in good position The ankle joint mortise is well preserved and simple immobilization in a short leg cast is all that is necessary

Fig 442 Abduction fracture of the medial malleolus The fracture has occurred just above the tip of the malleolus is transverse in direction and the mortise of the ankle joint is preserved by the base of the medial malleolus Simple cast immobilization is usually adequate to assure healing

be facilitated by holding the foot in slight adduction so as to relax the tibial collateral ligament If there is any doubt as to the validity of the bony contact, open operation for skeletal fixation, either by a wire suture or a screw, is indicated The leg should be immobilized in a plaster of Paris cast with the foot in slight adduction, and the cast should be left in place for a period of at least six weeks A walking iron or heel may be incorporated in the cast

Unimalleolar adduction fractures are transverse fractures of the lateral malleolus occurring at or below the level of the ankle joint (Fig 443) They should

Fig 443 Adduction fracture of the lateral malleolus There is slight lateral displacement of the fractured fragment but the integrity of the joint mortise is maintained The fractured fragment should be pushed medially to secure axial alignment and immobilization should be maintained with the foot in slight abduction for a period of three to four weeks A walking iron or heel may be incorporated in the short leg cast

be reduced in a slight degree of abduction, so as to relax the fibular collateral ligament Union usually occurs after simple immobilization in a walking plaster of Paris boot for a period of three or four weeks

Bimalleolar fractures below the level of the ankle joint, usually require no reduction and should be immobilized in a plaster of Paris cast for a period of about six weeks After this active motion without weight bearing should be instituted for a period of an additional four to six weeks, when bony union is usually complete (see Fig 450)

Longitudinal Fractures

Longitudinal fractures of the lower end of the tibia result from upward impaction of the astragalus against the inferior articular surface of the tibia When

the foot is in dorsiflexion at the time of injury, the fracture usually involves the *anterior margin* of the tibia When the injury is sustained with the foot in plantar flexion, posterior marginal fractures usually result Small fractures of the anterior margin are not uncommon in football and soccer players, and have been designated as footballer s ankle (Figs 444 and 445)

Fractures of the posterior lip are the more frequent type Where the fragment is small, nothing more than immobilization is necessary and union is usually com-

Fig 444 Footballer s ankle There is a small fracture of the anterior surface of the tibia just above the ankle joint There is minimal displacement of the fragment and simple immobilization either with an adhesive tape dressing or a light plaster cast usually suffices

Fig 445 Footballer s ankle A small fragment of the anterior margin of the tibia has been fractured No treatment other than rest is indicated

plete in about six weeks (Fig 446) Where the fragment is large however and involves more than 25 per cent of the surface of the lower tibial articulation, open operation for accurate replacement and skeletal fixation of the fragment is necessary (Fig 447) In such event immobilization in a short leg cast should be maintained for a period of at least six weeks Thereafter active motion without weight bearing may be instituted Weight bearing should be prohibited until there is evidence of firm bony union Failure to secure accurate reposition and firm fixation almost invariably results in a traumatic osteoarthritis (Fig 448)

Fig 446 Posterior marginal fracture of the tibia There is a spiral fracture of the fibula associated with a posterior marginal fracture of the inferior surface of the tibia Treatment consisted of reduction of the fibular fracture and immobilization in a plaster of Paris cast No specific treatment of the tibia was indicated

Fig 447 Posterior marginal fracture of the tibia There is an external rotation fracture of the fibula with a fracture of the posterior margin of the tibia involving almost half the inferior articular surface of the tibia The tibial fracture was reduced at open operation and fixed by means of a screw No skeletal fixation was necessary for the fibular fracture

Fig. 448. Anterior marginal fracture of the tibia. The fracture involves about a third of the inferior articular surface of the tibia. It was not accurately reduced and a painful traumatic osteoarthritis resulted.

Fig. 449. Fracture of Tillaux tubercle. There is an oblique fracture of the lateral portion of the lower end of the tibia without marked displacement or disruption of the tibiofibular ligament and ankle joint mortise. Simple immobilization in a plaster boot is indicated.

An interesting and unusual type of longitudinal fracture is represented by *fracture of Tillaux tubercle* the lateral projection of the inferior portion of the tibia, which is grooved for articulation with the fibula (Fig 449) This fracture is frequently overlooked and is often misdiagnosed as a chronic sprain of the ankle unless x-rays are taken with the foot in internal rotation so as clearly to expose the mortise of the ankle joint and, particularly, the inferior tibiofibular articulation Where there is no marked displacement, immobilization in a short plaster of Paris leg cast for a period of about six weeks or until firm bony union has occurred results in adequate healing Where there is displacement with diastasis of the ankle joint mortise, open operation and fixation by a screw passed through the tibia into

FIG 450 Bimalleolar fractures below the level of the ankle joint There are fractures of the tips of both malleoli The ankle mortise is entirely preserved and immobilization in a plaster of Paris cast resulted in satisfactory healing

the fibula are necessary Active motion may be instituted after six weeks but weight bearing should be deferred until there is evidence of firm bony union

FRACTURES THAT DISRUPT THE ANKLE JOINT MORTISE

The stability of the ankle joint is maintained by the integrity of the bony mortise the collateral ligaments and the inferior tibiofibular ligament While injury to the collateral ligaments may lead to chronic sprain and weakness of the ankle joint injuries to the tibiofibular ligament or to the malleolar structures lead to a widening of the mortise instability of the ankle and, unless satisfactorily corrected to a traumatic arthritis of the ankle joint Fractures that disrupt the mortise are therefore fracture-dislocations and not simple fractures of the ankle

In general, these may be divided into two main types (1) lateral or medial dislocations resulting from bimalleolar fractures or unimalleolar fractures with rupture of the opposite collateral ligament and (2) anteroposterior dislocations resulting from fractures of the anterior or posterior margins of the tibia in association with factures of one or both of the malleoli

Lateral or Medial Fracture-dislocations

Lateral or medial fracture-dislocations may result from external rotation or from abduction or adduction forces acting against the malleoli The fracture lines always occur *above* the level of the superior articular surface of the astragalus

External rotation fracture dislocations of the ankle are characterized by a spiral fracture of the lower end of the fibula, usually above the level of the tibiofibular joint and either a transverse or oblique fracture of the medial malleolus (Fig 451) or a rupture of the tibial collateral ligament, the equivalent of a fracture of the medial malleolus (Fig 452) Anatomical re establishment of the mortise is essential This can usually be accomplished by internal rotation with pressure against the lateral malleolus Care must be exercised however to avoid overcorrection and the creation of the opposite type of displacement When satisfactory reduction has been achieved a short leg cast should be applied and left in place for a period of at least six weeks after which active motion without weight bearing may be begun If accurate reduction cannot be obtained open operation with skeletal fixation usually of the medial malleolus should be undertaken (Fig 453)

Fig 451 External rotation fracture dislocation of the ankle There is a spiral fracture of the lateral malleolus above the level of the inferior tibiofibular joint and a transverse fracture of the medial malleolus at the level of the ankle joint There is lateral displacement of the foot

Open operation can be performed through a small longitudinal or horseshoe-shaped incision directly exposing the malleolus The small fragment is manipulated into position and a Kirschner wire is then passed through the malleolus up into the shaft of the involved tibia X ray examination should be made to verify the accuracy of the reduction Only if the alignment is satisfactory should the fragment be finally fixed in place Where a long screw is used, care should be taken to avoid penetration of the ankle joint and the screw should be sufficiently long to engage well up into the shaft of the bone and preferably, the opposite cortex Fixation may also be obtained by means of a vertical mattress suture but this is not as sat-

Fig 452 External rotation fracture dislocation of the ankle There is a spiral fracture of the lateral malleolus above the level of the tibio fibular joint with outward displacement of the foot There is no evidence of fracture of the medial malleolus and the lateral displacement must be attributed to a rupture of the tibial collateral ligaments (*left*) The fracture was reduced and held in place by screw fixation of the fibula with com plete restoration of the joint mortise (*right*)

Fig 453 External rotation frac ture dislocation of the ankle Follow ing reduction of the fracture by manip ulation the medial malleolus was fixed by means of a vertical mattress wire suture

isfactory as a screw fixation Following fixation, the leg should be immobilized in a short leg cast with the foot in the neutral position for a period of about six weeks, after which active motion without weight bearing may be gradually re-sumed

Abduction fracture dislocations are characterized by a transverse fracture of the medial malleolus usually at the level of the ankle joint with an additional transverse or oblique fracture of the lateral malleolus at or above the level of the ankle joint, with lateral dislocation of the foot Reduction is accomplished by ad-duction of the foot Where the fracture of the medial malleolus is below the level

of the ankle joint excessive adduction is prevented by impingement of the medial wall of the astragalus against the remnant of the base of the medial malleolus Where however the fracture of the medial malleolus is at or above the level of the ankle joint special care must be taken to prevent excessive adduction While these fractures can be treated by closed manipulative methods open operation with screw fixation of the medial malleolus affords a more expeditious method of treatment As in other fracture-dislocations about the ankle joint plaster cast immobilization should be maintained for a period of about six weeks after which active

FIG 454 Pott s or Dupuytren s fracture There is a high fracture of the fibula diastasis of the inferior tibiofibular joint an abduction fracture of the medial malleolus and a widening of the ankle joint mortise This could not be reduced by closed manipulation The fibular fracture was reduced at open operation and was then fixed by a screw passing through the fibula into the tibia at the level of the inferior tibiofibular articulation The medial malleolus was reduced and held in position by an additional screw The leg was immobilized in a short plaster of Paris leg cast

motion, without weight bearing may be permitted until firm bony union has occurred Thereafter gradual weight bearing with the aid of a cane may be instituted

Pott s or Dupuytren s fracture constitutes a special type of abduction fracture-dislocation characterized by a transverse fracture of the medial malleolus with rupture of the inferior tibiofibular ligament leading to diastasis of the ankle and in consequence of this an inward bending of the fibula that in turn, leads to an oblique fracture of the fibula about two inches above the level of the ankle joint (Fig 454) These fractures may be treated by closed methods provided that great care is taken to compress the inferior tibiofibular joint so as to overcome the diastasis of the mortise Usually however, a more satisfactory fixation of this joint

FIG 452 External rotation fracture dislocation of the ankle There is a spiral fracture of the lateral malleolus above the level of the tibio fibular joint with outward displacement of the foot There is no evidence of fracture of the medial malleolus and the lateral displacement must be attributed to a rupture of the tibial collateral ligaments (*left*) The fracture was reduced and held in place by screw fixation of the fibula with com plete restoration of the joint mortise (*right*)

FIG 453 External rotation frac ture dislocation of the ankle Follow ing reduction of the fracture by manip ulation the medial malleolus was fixed by means of a vertical mattress wire suture

isfactory as is screw fixation Following fixation, the leg should be immobilized in a short leg cast with the foot in the neutral position for a period of about six weeks after which active motion without weight bearing may be gradually re sumed

Abduction fracture-dislocations are characterized by a transverse fracture of the medial malleolus, usually at the level of the ankle joint with an additional transverse or oblique fracture of the lateral malleolus at or above the level of the ankle joint with lateral dislocation of the foot Reduction is accomplished by ad duction of the foot Where the fracture of the medial malleolus is below the level

with alignment of the fibular fracture and restoration of the lateral buttress of the ankle mortise can be accomplished by screw fixation of the tibia and fibula at the level of the inferior tibiofibular joint The screw should be inserted from the fibular side and should be sufficiently long as to engage the medial cortex of the tibia This frequently suffices to permit realignment of the medial malleolus If not, the medial malleolus may be additionally fixed by a wire suture or obliquely directed screw (Fig 455)

Adduction fracture-dislocations are characterized by a transverse fracture of the lateral malleolus with a transverse or oblique fracture of the medial malleolus and medial dislocation of the foot (Fig 456) As in other adduction fractures, these may be reduced by abducting the foot, care being taken to avoid overcorrection of the deformity If accurate anatomical reposition cannot be obtained, open operation and screw fixation of either of the malleoli is indicated In any event, postreduction immobilization should be continued as for all other fractures about the ankle

Anteroposterior Fracture-Dislocations

Anteroposterior fracture-dislocations are predicated primarily upon a fracture involving either the anterior or posterior margin of the lower end of the tibia in association either with rupture of one or more of the collateral ligaments or fracture of one or both of the malleoli Where the anterior tibial margin is fractured, dislocation of the foot usually occurs anteriorly where the posterior lip is fractured, the foot is usually displaced posteriorly (Fig 457) The associated fracture of the malleoli may be either of the external rotation, abduction or adduction type and treatment must be directed first toward reduction of the dislocation and there-

Fig 457 Posterior fracture dislocation of the ankle There is a spiral external rotation fracture of the lower end of the fibula with a fracture of a small portion of the posterior margin of the tibia (*left*) Closed reduction is usually satisfactory in these cases provided that the dislocation is reduced before the fractured fibula is realigned (*right*)

FIG 455 Abduction fracture dislocation of the ankle There is an oblique fracture of the lower end of the fibula and a transverse fracture of the medial malleolus with lateral dislocation of the foot The fracture was reduced and the medial malleolus was fixed by a screw that passes upward into the tibia without involvement of the ankle joint

FIG 456 Adduction fracture dislocation of the ankle There is a transverse fracture with epiphyseal separation of the lateral malleolus The foot has been displaced medially and has resulted in an unusual longitudinal fracture across the lower tibial epiphysis Despite satisfactory reduction premature synostosis of the inferior tibial epiphysis occurred leading to retardation of growth and the development of a varus deformity at the ankle (See Fig 435)

FIG 460 Cotton s trimalleolar fracture There is an external rotation fracture of the lateral malleolus with a transverse fracture of the medial malleolus and a large posterior marginal fracture This was reduced by open operation with screw fixation The medial malleolus was subsequently fixed by a wire suture with restoration of the ankle joint mortise

FIG 461 Malunited Pott s fracture In addition to the fracture of the medial malleolus diastasis at the inferior tibiofibular joint and high fracture of the fibula there is also a posterior marginal fracture of the tibia with posterior dislocation of the foot This fracture was improperly treated by closed methods with resultant disturbance of mortise malalignment of fibula and a painful traumatic osteoarthritis of ankle joint

FIG. 458. Unusual quadrimalleolar fracture. There is an abduction fracture of the malleoli with both anterior and posterior marginal fractures in good position. The anterior and posterior marginal fragments required no reduction and the bimalleolar fracture was treated by closed reduction. (*Left*) Anteroposterior view. (*Right*) Lateral view.

FIG. 459. Cotton's trimalleolar fracture. There is abduction fracture of the medial malleolus with an oblique fracture of the lateral malleolus and a posterior marginal fracture involving more than half the inferior articular surface of the tibia. This required open operation and screw fixation of the posterior marginal fragment. The medial malleolus was fixed by a screw and the foot was immobilized in slight adduction.

In all the fracture-dislocations about the ankle, a painful posttraumatic arthritis of the ankle joint is an almost certain sequel unless accurate anatomical realignment is achieved (Fig 461) Arthrodesis then offers the only hope for the relief of symptoms (Fig 462)

FIG 463 Rupture of the inferior tibiofibular ligaments Widening of the mortise and instability in the ankle joint may arise as a result of rupture of the inferior tibiofibular ligaments Existence of rupture is betrayed by widening of the inferior tibiofibular joint It may lead to a painful arthritis in this joint that can be controlled only by bolt fixation of the joint

Widening of the mortise of the ankle joint may result from rupture of the inferior tibiofibular ligaments in the absence of any bony injury and may lead to instability and a painful arthritis in this joint The symptoms may be controlled by bolt fixation of the inferior tibiofibular joint (Fig 463)

after to the specific treatment of the fracture type Reduction of the dislocation can be accomplished by traction in the axis of the leg and by manual pressure directed either posteriorly or anteriorly against the foot Where the fracture of the margin of the tibia involves more than 25 per cent of the total articular surface, screw fixation of the fragment must be undertaken Thereafter immobilization is identical with that previously described for other fractures about the ankle joint

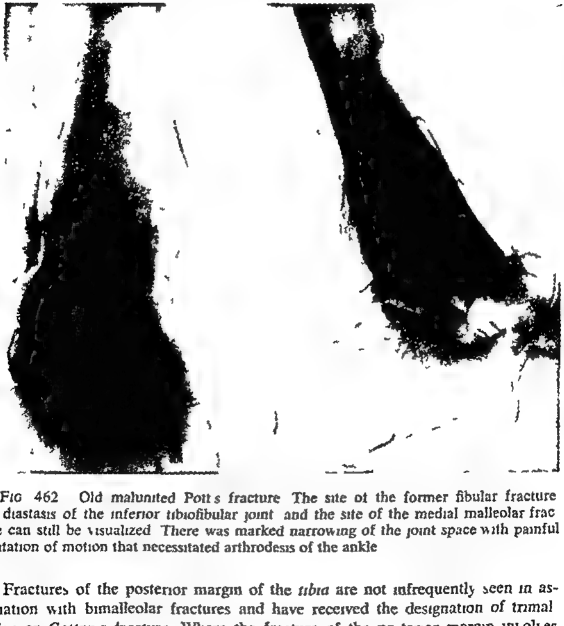


FIG 462 Old malunited Pott s fracture The site of the former fibular fracture the diastasis of the inferior tibiofibular joint and the site of the medial malleolar fracture can still be visualized There was marked narrowing of the joint space with painful limitation of motion that necessitated arthrodesis of the ankle

Fractures of the posterior margin of the *tibia* are not infrequently seen in association with bimalleolar fractures and have received the designation of trimalleolar or *Cotton s fracture* Where the fracture of the posterior margin involves less than 25 per cent of the inferior articular surface of the tibia attention must be directed primarily to the treatment of the malleolar fractures This may be accomplished by closed reduction (Fig 458) Where, however the posterior fragment involves more than 25 per cent of the tibial articular surface (Fig 459) it is essential to reduce and fix the posterior marginal fracture before directing attention to the bimalleolar fracture (Fig 460)

FIG 464 Tuber joint angle On the lateral roentgenogram of the foot a line drawn from the tip of the tuberosity to the posterior articular facet of the os calcis makes an angle of thirty five to forty degrees with a line drawn from the posterior articular facet to the upper border of the anterior portion of the os calcis Angles of less than this magnitude are indicative of fracture of the os calcis

When either the tuberosity or the anterior portion of the os calcis are displaced upward or when the posterior facet is compressed and displaced downward the tuber-joint angle is flattened and becomes incongruent with the undersurface of the overlying astragalus As the upper surface of the body of the os calcis is depressed, the lateral walls bulge, leading to a widening of the heel (Fig 465) While this widening of the heel may lead to subsequent difficulty, particularly in the fitting of shoes it is the disruption of the astragalocalcaneal joint that is the determining element in the ultimate outcome of calcaneal fractures

Regardless of the anatomical restitution that may be accomplished by manipulative efforts the subsequent development of a tramatic arthritis in this joint is not infrequent Conversely although it would appear inconceivable that an injury so severe as to mutilate the contour of the bone could occur without extensive damage to the articulation between the os calcis and the astragalus there are many patients in whom the tuber-joint angle has not been restored and who are able to resume relatively normal use of the foot with but little difficulty It is impossible to forecast the outcome of an os calcis fracture merely from its roentgenographic appearance

Where fracture of the os calcis has occurred with no or slight displacement of the fragments and no distortion of the tuber-joint angle little is necessary beyond

CHAPTER 23

Fractures of the Foot

Fractures of the foot include fractures of the tarsal bones, the metatarsal bones, and the phalanges They arise as a result of severe crushing injuries or from falls from a height, in which the patient lands directly upon the feet Not infrequently such injuries are associated with injuries elsewhere, as at the upper end of the femur and, particularly, the lumbar spine The history of such an injury should always indicate the necessity for careful examination of these areas before instituting treatment of the foot condition Depending upon the severity and direction of the fracturing force, displacement of the fractured fragments may be so slight as to defy diagnosis even after x ray examination or so great as to lead to complete distortion of the foot

Fractures of the Tarsus

Fractures of the tarsus involve primarily the os calcis Fractures of the astragalus may occur, but are proportionately infrequent, and fractures of the other bones of the tarsus must be considered as exceedingly rare

Fractures of the Os Calcis

Fractures of the body of the os calcis (calcaneus) acquire their particular significance because of the resultant disruption of the astragalocalcaneal (subastragalar) joint Weight bearing and inversion or eversion of the foot are mediated across this joint and any loss of anatomical configuration or destruction of the articular surface necessarily leads to the possibility of painful limitation of motion The most important of the os calcis fractures consequently are those that involve the body of the bone with loss of the so called tuber-joint angle

Normally, a line drawn from the tip of the tuberosity to the upper portion of the posterior articular facet of the os calcis makes an angle of about forty degrees with a line drawn from the posterior articular facet to the upper border of the anterior portion of the os calcis (tuber-joint angle) (Fig 464)

body of the os calcis This does not seem to be a desirable approach, first, because of the fact that a disabling arthritis is not an invariable sequel of the fracture, and second, because of the technical difficulties involved If operated upon shortly after the fracture, the operative field presents a soupy mass in which it is almost impossible to identify anything but the inferior surface of the astragalus It is far better to wait for a period of six to nine months after fracture before contemplating operative intervention for functional impairment If pain and disability still persist, subastragalar fusion must then be undertaken

Fractures of the anterior portion of the os calcis are relatively rare Their importance lies in the fact that the anterior portion articulates with the cuboid and

FIG 466 Fracture of the os calcis with astragalonavicular dislocation The anterior portion of the os calcis has been fractured and displaced downward by continuance of the force that has resulted in a dislocation at the astragalonavicular joint (talo navicular joint)

supports the head of the astragalus Loss of this latter support leads to the development of a traumatic flat foot or the appearance of a traumatic arthritis of the calcaneocuboid joint Where the distal fragment is displaced downward there may be an associated dislocation at the astragalonavicular joint (Fig 466) In such event closed reduction of the dislocation may serve to replace the fractured anterior fragment When this is impossible, open operation may be necessary After reduction, the treatment should be the same as for fractures of the body If arthritic symptoms develop, fusion of the involved articulation usually leads to subsidence of symptoms

The *tuberosity or posterior portion of the os calcis* may be the site of two different types of fracture (1) avulsion of the apophysis or (2) the "beak" fracture In the *avulsion of the apophysis* where the fragment is displaced upward, the pull

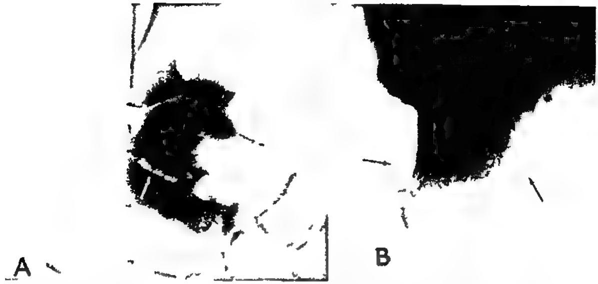


FIG 465 Fracture of the os calcis The tuber joint angle is reduced to eight degrees owing to compression of the superior articular surface (*A*) On the special plantar dorsal view taken with the foot in dorsiflexion and the central x ray beam directed obliquely toward the heel bulging of the lateral walls of the os calcis owing to axial fractures can be seen (*B*)

simple immobilization of the foot in a short plaster of Paris boot Where, however, the tuber-joint angle has been reduced an effort at anatomical restitution of the fragments may be made

The primary step in the treatment of these fractures is the breaking of the impaction between the fragments This may be accomplished with the knee flexed and the foot in plantar flexion to relax the Achilles tendon Great force is frequently necessary to disimpact the fracture and it is important to avoid damage to the ankle joint by firmly grasping the joint and directing the disimpacting force solely against the os calcis This may be facilitated by permitting only the os calcis to project beyond the table upon which the reduction is carried out If complete disimpaction can be achieved, an effort to restore the tuber-joint angle may be made by plantar flexing the front and hind parts of the foot over a wedge or a bar placed against the sole of the foot in the plane of the axis of the leg The tuber-joint angle should be increased to slightly beyond the normal forty degrees The increase in the width of the os calcis may be overcome either by using a carpenter's clamp to compress the walls of the os calcis or by a mallet blow against the adequately padded lateral surface of the bone

If satisfactory anatomical restoration has been accomplished, the foot should be immobilized in a short plaster of Paris boot for a period of at least six weeks At the end of this time the cast may be removed to permit active motion of the foot and ankle but weight bearing should not be permitted for at least another month or until there is evidence of healing Thereafter weight bearing with crutches and later without crutches should be instituted

Because of the severe disability that frequently follows these fractures, some surgeons have advised primary fusion of the subastragalar joint in fractures of the

body of the os calcis This does not seem to be a desirable approach, first, because of the fact that a disabling arthritis is not an invariable sequel of the fracture, and second, because of the technical difficulties involved If operated upon shortly after the fracture, the operative field presents a soupy mass in which it is almost impossible to identify anything but the inferior surface of the astragalus It is far better to wait for a period of six to nine months after fracture before contemplating operative intervention for functional impairment If pain and disability still persist, subastragalar fusion must then be undertaken

Fractures of the anterior portion of the os calcis are relatively rare Their importance lies in the fact that the anterior portion articulates with the cuboid and

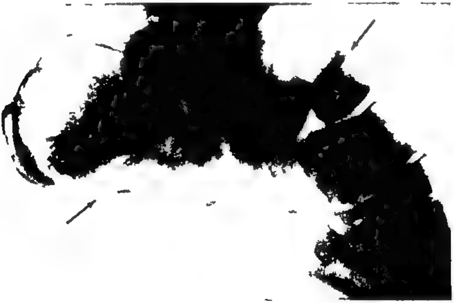


Fig 466 Fracture of the os calcis with astragalonavicular dislocation The anterior portion of the os calcis has been fractured and displaced downward by continuance of the force that has resulted in a dislocation at the astragalonavicular joint (talo navicular joint)

supports the head of the astragalus Loss of this latter support leads to the development of a traumatic flat foot or the appearance of a traumatic arthritis of the calcaneocuboid joint Where the distal fragment is displaced downward there may be an associated dislocation at the astragalonavicular joint (Fig 466) In such event closed reduction of the dislocation may serve to replace the fractured anterior fragment When this is impossible, open operation may be necessary After reduction the treatment should be the same as for fractures of the body If arthritic symptoms develop fusion of the involved articulation usually leads to subsidence of symptoms

The *tuberosity or posterior portion of the os calcis* may be the site of two different types of fracture (1) avulsion of the apophysis or (2) the beak' fracture In the *avulsion of the apophysis* where the fragment is displaced upward, the pull

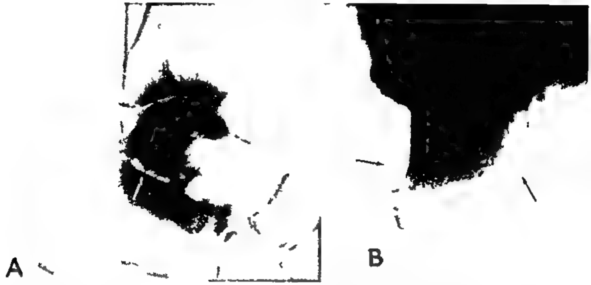


FIG 465 Fracture of the os calcis The tuber joint angle is reduced to eight degrees owing to compression of the superior articular surface (*A*) On the special plantar dorsal view taken with the foot in dorsiflexion and the central x ray beam directed obliquely toward the heel, bulging of the lateral walls of the os calcis owing to axial fractures can be seen (*B*)

simple immobilization of the foot in a short plaster of Paris boot Where, however the tuber-joint angle has been reduced an effort at anatomical restitution of the fragments may be made

The primary step in the treatment of these fractures is the breaking of the impaction between the fragments This may be accomplished with the knee flexed and the foot in plantar flexion to relax the Achilles tendon Great force is frequently necessary to disimpact the fracture and it is important to avoid damage to the ankle joint by firmly grasping the joint and directing the disimpacting force solely against the os calcis This may be facilitated by permitting only the os calcis to project beyond the table upon which the reduction is carried out If complete disimpaction can be achieved, an effort to restore the tuber-joint angle may be made by plantar flexing the front and hind parts of the foot over a wedge or a bar placed against the sole of the foot in the plane of the axis of the leg The tuber-joint angle should be increased to slightly beyond the normal forty degrees The increase in the width of the os calcis may be overcome either by using a carpenter's clamp to compress the walls of the os calcis or by a mallet blow against the adequately padded lateral surface of the bone

If satisfactory anatomical restoration has been accomplished the foot should be immobilized in a short plaster of Paris boot for a period of at least six weeks At the end of this time the cast may be removed to permit active motion of the foot and ankle but weight bearing should not be permitted for at least another month or until there is evidence of healing Thereafter, weight bearing with crutches and later without crutches should be instituted

Because of the severe disability that frequently follows these fractures some surgeons have advised primary fusion of the subastragalar joint in fractures of the

FIG 468 Fracture of the sustentaculum tali The sustentaculum is oblique and is not located as normally beneath the head of the talus which it supports

forefoot should be strongly pronated while upward pressure is made on the inner aspect of the foot against the fractured fragment If reduction is successful, the foot should be immobilized in a plaster of Paris boot that should be left on for at least six weeks When weight bearing is to be resumed, the patient should be fitted with a foot plate to support the longitudinal arch of the foot

FRACTURES OF THE ASTRAGALUS

Fractures of the astragalus, though more common than those of the other tarsal bones, are far less frequent than fractures of the os calcis They usually result from falls upon the feet and may involve the body, neck or posterior process

Fracture of the body may be simple or comminuted In the simple fractures, there is little tendency toward displacement and treatment consists of simple immobilization for a period of six to eight weeks Though active motion may be permitted after six weeks weight bearing should not be permitted for at least eight weeks

Where the body is severely comminuted an effort should be made to reduce the fragments by skeletal traction applied through a wire passed through the os calcis while the foot is gently manipulated through flexion extension, inversion, and eversion If displacement is so great that reduction cannot be accomplished by manipulation the outlook is serious not only because of the displacement but also because of the impairment of the circulation in the astragalus that must be predicated Open operation for reduction of the fragments may be undertaken but with realization of the fact that ischemic necrosis of the bone with the subsequent development of an arthritis is not unlikely Arthritis may involve either or both the ankle and the subastragalar joints Arthrodesis of the involved joint or even panarthrodesis of the astragalus is to be preferred to astragalectomy that in the adult yields at best indifferent results

of the Achilles tendon acts as the fracturing force The line of fracture is longitudinal and, in children, follows rather accurately the line of the calcaneal apophysis Even in adults, after closure of the apophyseal line, the avulsion fracture occurs through or near the former location of the apophysis

Where the fragment is displaced downward, the Achilles tendon cannot be considered as the disrupting force In either event, it is desirable to replace the fragment to avoid the possibility of excessive callus formation and difficulty in wearing a shoe If replacement by closed manipulation is impossible, open operation and skeletal fixation of the fragment is indicated

Fig 467 Beak fracture of the os calcis The fracture line is horizontal and the small fragment is usually displaced upward This may be reduced by closed manipulation or if that is unsuccessful by skeletal fixation

The *horizontal or beak fracture of the tuberosity* is, in all probability, not due to the pull of the Achilles tendon, since the fracture line is usually situated above that portion of the tuberosity into which the tendon is inserted (Fig 467) Failure to reduce this fracture may lead to discomfort in the wearing of a shoe Reduction may be accomplished by plantar flexing the foot while pressure is made on the small fragment If this is unsuccessful, more direct pressure against the small fragment may be exerted by downward pressure of a sound or heavy wire passed above the fragment in front of the Achilles tendon Where neither of these methods is successful the fragment may be exposed and wired into place through a small incision along the outer side of the Achilles tendon

Isolated fracture of the sustentaculum tali is extremely rare (Fig 468) It results from a fall upon the inverted foot and is caused by the impact of the head of the astragalus Since its function is support of the head of the astragalus, failure to replace the fractured fragment leads to a disabling type of traumatic flat foot Reduction may be accomplished by plantar flexing and inverting the hind foot The

FIG 470 Avulsion fracture of the astragalus There is upward displacement of a small flake of the dorsal aspect of the neck of the astragalus probably owing to avulsion by the attachment of the capsular ligament The leg should be immobilized in dorsiflexion to prevent excess callus formation in the vicinity of the astragalo navicular joint

FIG 471 Fracture of the astragalus There is a fracture of the lateral mass of the astragalus that has healed with excess callus formation

FIG 472 Shepherd's fracture of the astragalus The processus posticus has been fractured and displaced upward The margins of the fracture are sharp as contrasted with the smooth contour presented by a normal os trigonum

Fracture of the neck of the astragalus is the most common of all fractures of this bone, and results from a fall on the dorsiflexed foot The body of the bone is held fixed between the ankle mortise and the os calcis while the anterior portion of the os calcis exerts a shearing action on the astragalar neck that is usually displaced upward (Fig 469) Appreciation of this mechanism is essential to proper treatment of the fracture The fracture must first be disimpacted by manipulation Thereafter, the forefoot must be pulled into marked plantar flexion so as to permit realignment of the head and neck with the body of the astragalus The foot and leg should be immobilized in a short plaster of Paris boot that should be left undisturbed for a

FIG 469 Fracture of the astragalus There is a fracture of the neck of the astragalus with upward displacement of the distal fragment This can be re duced only by marked plantar flexion of the foot

period of about six weeks Active motion without weight bearing may be permitted after six weeks but weight bearing should be avoided for about another month and then only with the aid of a foot plate to support the longitudinal arch

Avulsion fracture of the neck of the astragalus probably results from the pull of the attached capsule of the ankle joint (Fig 470) Displacement is usually minimal but immobilization in the position of dorsiflexion is desirable to prevent excess callus formation near the astragalonavicular joint

Occasionally the *lateral mass for the fibular articulation* may be fractured by excessive inversion of the foot (Fig 471) This fracture is frequently unrecognized but when diagnosed requires nothing more than immobilization of the foot in the neutral position for control of pain

Fracture of the processus posticus (Shepherd s fracture) (Fig 472) is significant primarily because of its medicolegal implications It results from impac-

FIG 474 Fracture of the cuboid There is a crush fracture of the bone with lateral displacement of a small fragment

FRACTURES OF THE METATARSAL BONES

Fractures of the metatarsal bones may occur at either end or in the shaft of the bone Except for the fifth metatarsal, fracture of the base *is extremely uncommon* Fracture of the base of the fifth metatarsal, on the other hand, is frequent (Fig 475) It may result from a misstep and is possibly due to avulsion by the peroneus brevis tendon which is inserted into the base of the fifth metatarsal bone The displacement is usually minimal but unless properly immobilized may lead to a prolonged disability Simple strapping is insufficient, but prompt relief of pain with healing of the fracture occurs after immobilization in a plaster of Paris boot for a period of four to six weeks

Fracture of the shaft of the metatarsal bones is usually oblique with little separation of the fragments If there is no displacement, the foot should be immobilized in a plaster of Paris boot for a period of four to six weeks If there is a displacement, reduction may be accomplished by traction through a banjo splint similar to that used in fractures of the metacarpal bones

A special form of fracture of the metatarsal bones has been designated as *march or stress fracture* (Fig 476) It is subperiosteal in nature and is characterized by pain and a periosteal proliferation at the site of fracture Displacement does not occur but, unless the foot is put at complete rest, the pain persists and excess callus, occasionally sufficient to interfere with the digital circulation, may be formed Treatment is by immobilization in a plaster of Paris boot until all pain has subsided

Fractures of the distal ends of the metatarsal bones are of fairly frequent occurrence and their proper reduction is of the utmost importance in maintaining normal function of the foot Contrary to popular belief about the anterior transverse arch of the foot the heads of the metatarsal bones all lie in the same plane and they must be restored to this position following fracture This can only be assured by the use of the footboard (Fig 92) when postreduction immobilization is undertaken

tion of the process against the posterior rim of the tibia during marked plantar flexion No treatment other than simple immobilization for three to four weeks is usually necessary Where pain persists, the fragment may be removed Care must be taken to differentiate this fracture from the appearance of an accessory bone, the os trigonum, that is frequently normally present In a true fracture, the separation between the small fragment and the body of the bone is small and the bone edges are sharp as compared with the smooth appearance noted bilaterally in cases of os trigonum

Fractures of the Navicular

Fractures of the navicular may result from a fall on the adducted forefoot (Fig 473) The tuberosity of the bone is compressed between the astragalus and the

Fig 473 Fracture of the navicular The tuberosity and medial half of the navicular have been compressed and displaced slightly medially

medial cuneiform bones Displacement is usually slight and immobilization for a period of four to six weeks in a plaster of Paris boot followed by weight bearing on a foot plate suffices to restore normal function of the foot Where there is displacement of the tuberosity digital pressure frequently leads to reduction If arthritis develops between the astragalar head and the navicular bone arthrodesis of this joint may be necessary

Fractures of the Cuboid

Isolated fracture of the cuboid as of the cuneiform is exceedingly rare Displacement is minimal and treatment is directed toward the control of pain by a plaster of Paris boot for a period of four to six weeks (Fig 474)

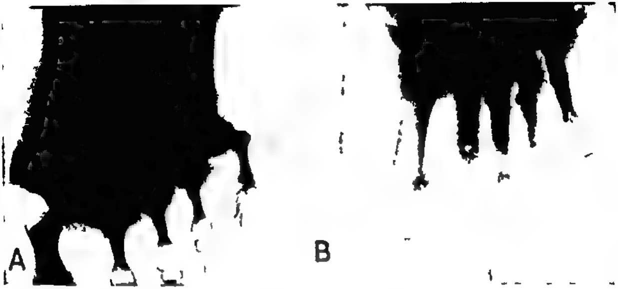


FIG 477 Multiple metatarsal fractures Fractures have occurred through the necks of the second third and fourth metatarsals with a dislocation of the fifth toe (*A*) Reduction was accomplished by open operation and bone suture (*B*)

FIG 478 Freiberg s infraction The head of the third metatarsal the characteristically involved site is flattened and a transverse fracture line in the subchondral region is visible

fifth toes (Fig 477*B*) The foot should be immobilized in a plaster of Paris boot Healing sufficient to permit weight bearing is usually complete within four to six weeks

Infraction of the head of the third metatarsal is occasionally seen (Fig 478) This condition (*Freiberg s infraction*) is usually seen in adolescents and may lead to considerable pain Symptoms subside under simple cast immobilization

FRACTURES OF THE PHALANGES

Fractures of the phalanges usually occur as the result of direct violence The line of fracture may be transverse or oblique In the former instance reduction can

FIG 475 Fracture of base of fifth metatarsal Fracture of the base of this bone is common and displacement is usually minimal Unless immobilized in a plaster of Paris boot healing is de layed and pain persists

FIG 476 , March fracture of the second metatarsal No fracture line is visible but there is periosteal new bone growth Treatment is by simple immobilization in a plaster boot with the foot in the neutral position

When multiple metatarsal head or neck fractures occur the distal fragments are usually displaced laterally (Fig 477*A*) This seems to be due to the pressure exerted by abduction of the big toe Occasionally, it is possible to overcome the distorting action of the big toe by its forcible adduction If this can be accomplished, the big toe should be held in the adducted position by incorporation in a separate plaster of Paris pocket with careful attention to maintaining the metatarsal heads in the same plane by use of the footboard Failure to assure this almost certainly leads to painful weight bearing and has resulted in the useless and harmful sacrifice of first one and then others of the metatarsal heads

Where it is impossible to secure accurate alignment of the metatarsal heads by this method open operation for accurate reposition and bone suture is indicated Open reduction can be carried out rather easily through two small incisions made in the dorsal interspaces between the second and third and between the fourth and

be accomplished by manipulation in the latter, displacement is usually slight (Fig 479) Immobilization for a period of three to four weeks can be accomplished either by a padded tongue-depressor splint applied to the plantar surface of the affected toe or by simply splinting the toe against the neighboring toes by an adhesive tape dressing Healing is usually complete within three weeks

Fractures of the terminal phalanges of the toes are usually comminuted as a result of severe compression injuries (Fig 480) The subungual hematoma that is almost invariably present is painful and may be carefully evacuated by excision of a portion of the nail if indicated The fractured fragments should then be molded into place and the toe should be protected by a metallic toe guard until healing has taken place

Fracture of the sesamoid of the big toe occasionally occurs and may be the cause of such pain as to require excision

FIG 479 Fracture of the proximal phalanx There is an oblique fracture of the shaft of the proximal phalanx of the fifth toe with practically no displacement Immobilization may be accomplished either by a plaster splint or by splinting the affected toe to its neighbor by adhesive tape

FIG 480 Comminuted fracture of the distal phalanx There is marked comminution of the tuft and shaft of the phalanx with but little displacement of the fragments Healing usually occurs following simple protection by a metallic toe guard

INDEX